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Volume Sensor Development Test Series 2 — Lighting Conditions, Camera Settings, and Spectral and Acoustic Signatures

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14. ABSTRACT

Real-scale fire tests in mock ship compartments were conducted to collect data of acoustic and spectral sensors and to experimentally evaluate the fire detection performance of three commercially available video image fire detection systems under various lighting and camera setting configurations. One goal was to establish an understanding of the performance sensitivity and limitations of the VID systems to various setup and environmental conditions that may occur onboard ship. The performance of the detection systems was compared to the response of multiple state-of-the-art smoke detection technologies for a range of fire and nuisance source exposures. Additionally, these tests provide a large database of information to evaluate the spectral and acoustic signatures of the various fire and nuisance sources. Toward this end, microphones, long wavelength video imaging and a test bed of single and multiple element sensors were included in the tests.

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ACRONYMS

ADC – Advanced Damage Countermeasures
AVI – Audio-Video Interleaved
BBB – Broad Band Blue
B/W – Black/White
CCTV – Closed Circuit Television
COTS – Commercial Off The Shelf
CVN – Carrier Vehicle Flight Nuclear
DAQ – Data Acquisition
DC – Damage Control
DoD – Department of Defense
DNA – Did Not Alarm
DV – Digital Vedeo
DVR – Digital Video Recorder
EST – Edwards System Technologies
Fc – Foot-candles
FOV – Field of View
FWD – Forward
FY – Fiscal Year
GUI – Graphical User Interface
IR – Infrared
LLW – Low Level White
LP – Long Pass (related to optical filters)
LWVD – Long Wavelength Video Detection
NA – Not Available
NFPA – National Fire Protection Association
NIR – Near Infrared
NRL – Naval Research Laboratory
NSTM – Naval Ships Technical Manual
ODM – Optical Density Meter
OFD – Optical Flame Detector
PC – Personal Computer
PD – Photodiode
PMT – Photomultiplier Tube
ROC – Receiver Operating Characteristic
SBVS – Spectral-Based Volume Sensor
SFA – Smoke and Fire Alert
SP – Short Pass (related to optical filters)
TC – Thermocouple
USB – Unweisal Serial Bus
UV – Ultra Violet
VS – Volume Sensor
VSD-8 – Visual Smoke Detection
VID – Video Image Detection
VIS – Visible

VOLUME SENSOR DEVELOPMENT TEST – LIGHTING CONDITIONS, CAMERA SETTINGS, AND SPECTRAL AND ACOUSTIC SIGNATURES

1.0 INTRODUCTION

The Advanced Damage Countermeasures program seeks to develop and demonstrate improved Damage Control (DC) capabilities. An important element of the ADC Program is the development of a volume sensor system that can assess damage conditions within a space without relying on a point measurement. The first phase of this program (FY01) consisted of a literature review and an industry review of current and emerging technologies [1]. Based on the FY01 work, several technologies were identified as having potential for meeting objectives of the volume sensor development effort. Work preformed during FY02 provided a basis for moving forward with the use of video image detection (VID) for shipboard applications [2]. The test results indicated that the VID systems using smoke alarm algorithms could provide equivalent detection compared to point detectors or spot-type smoke detectors for most of the conditions evaluated.

One task of the FY03 work was to evaluate video-based fire detection systems onboard the ex-USS *Shadwell*, the Naval Research Laboratory (NRL) full-scale fire research facility in Mobile, Alabama [3]. These systems were evaluated in two test series conducted 7-18 April and 21-25 April 2003, in which the detection systems were exposed to various fire and nuisance sources. The first test series was Test Series 2 of the CVN 21 Fire Threat to Ordnance program conducted April 7-18, 2003 [4]. During these tests, the video image fire detection systems were evaluated in an environment designed to represent storage onboard ships while exposed to two fire scenarios: adjacent space fires and in-space, wood crib fires [5]. Due to the limited fire scenarios that were conducted during the CVN21 Test Series 2, a separate test series was conducted specifically for the Volume Sensor program to provide a broader range of fire and nuisance source exposures. This second test series (a.k.a. Series VS1) was conducted on the ex-USS *Shadwell* on 21-25 April, 2003[6]. Analysis of the data from these shipboard tests indicated potential issues with VID performance relative to camera settings. These tests also identified potential advantages for the use of spectral and acoustic measurements as signatures of normal background conditions and fire and nuisance events [7, 8, 9, 10]. Additional tests were conducted at the Navy Wet Trainer in Baltimore, Maryland to record acoustical emissions and video of a range of pipe rupture and flooding events [11].

The test series of this report expands on the FY 03 test series conducted on the ex-USS *Shadwell*, mentioned above [6]. This test series evaluated video-based fire detection system performance when exposed to various fire and nuisance sources under varying light conditions and camera settings. Spectral and acoustic sensors were also evaluated in this test series to measure potential event signatures that could be integrated with the VID technology to expand the capabilities and to compensate for deficiencies with the current video image fire detection systems used for Navy applications. The data collected will be used to develop advanced algorithms for the volume sensor system. The majority of results of the spectral and acoustic sensor components will be presented in future reports, although some preliminary results are presented in this document.

2.0 OBJECTIVES

One objective of this test series was to experimentally evaluate the fire detection performance of three commercially available video image fire detection systems under various lighting and camera setting configurations. The goal was to establish an understanding of the performance sensitivity and limitations of the VID systems to various setup and environmental conditions that may occur onboard ship. The performance of the detection systems was compared to the response of multiple state-of-the-art smoke detection technologies for a range of fire and nuisance source exposures. A second objective of this test series was to evaluate the spectral and acoustic signatures of the various fire and nuisance sources. Toward this end, microphones, long wavelength video imaging, and a test bed of single and multiple element sensors were used.

3.0 APPROACH

The objectives were achieved by conducting full-scale experiments. Various VID and smoke detection technologies were installed in a compartment and a passageway mockup. The detectors were exposed to a broad range of fire and nuisance source exposures. This test series consisted of relatively small fires that served to challenge the detection systems. Besides the type of fire and nuisance sources, the following parameters were also systematically varied during the test series: the locations of the fires, lighting conditions, and camera settings.

4.0 TEST SETUP AND TEST PROCEDURES

The tests were conducted in a 10 m x 10 m x 3 m high (33 ft x 33 ft x 10 ft) test facility. Three compartments and a passageway were constructed within the facility to simulate various size ship spaces, that also roughly correspond in size to the spaces on the ex-USS *Shadwell* used in the previous testing [5, 6]. Figure 1 shows the layout. A summary of the test setup is provided in the following sections. As testing progressed and the data was analyzed, the use of the smaller test space as noted in the test plan [12] was not deemed necessary. Therefore, tests were conducted only in the large space and the passageway. As shown in Figure 1, the forward bulkhead of Compartment 1 was defined as the bulkhead on the far side of the compartment from the door to the passageway Test Spaces.

The overall dimensions of the test spaces are shown in Table 1. Compartment 1 is representative of the 3rd Deck Magazine located on the ex-USS *Shadwell*. The 3rd Deck Magazine aboard the ex-USS *Shadwell* has beams spanning port to starboard at 1.2 m (4 ft) spacing and depths of 30 cm (12.0 in) [6]. Compartment 1 contained “overhead beams” constructed of steel sheeting, Figure 2. These simulated “beams” created visible obstructions (camera line of sight) as well as physical obstructions to smoke travel in the overhead. The simulated beam obstructions were secured to the overhead with a spacing of 1.2 m (4 ft) and depths of 30 cm (12.0 in), the passageway had a smooth overhead. The compartments contained multiple visual obstructions such as electrical cabinets, chairs, tables, office equipment, cable trays and ductwork. The compartment conditions varied depending in part on outdoor conditions. The temperature ranged from approximately 18°C (65°F) to 32°C (90°F) and relative humidity levels range from 40% to 70%.

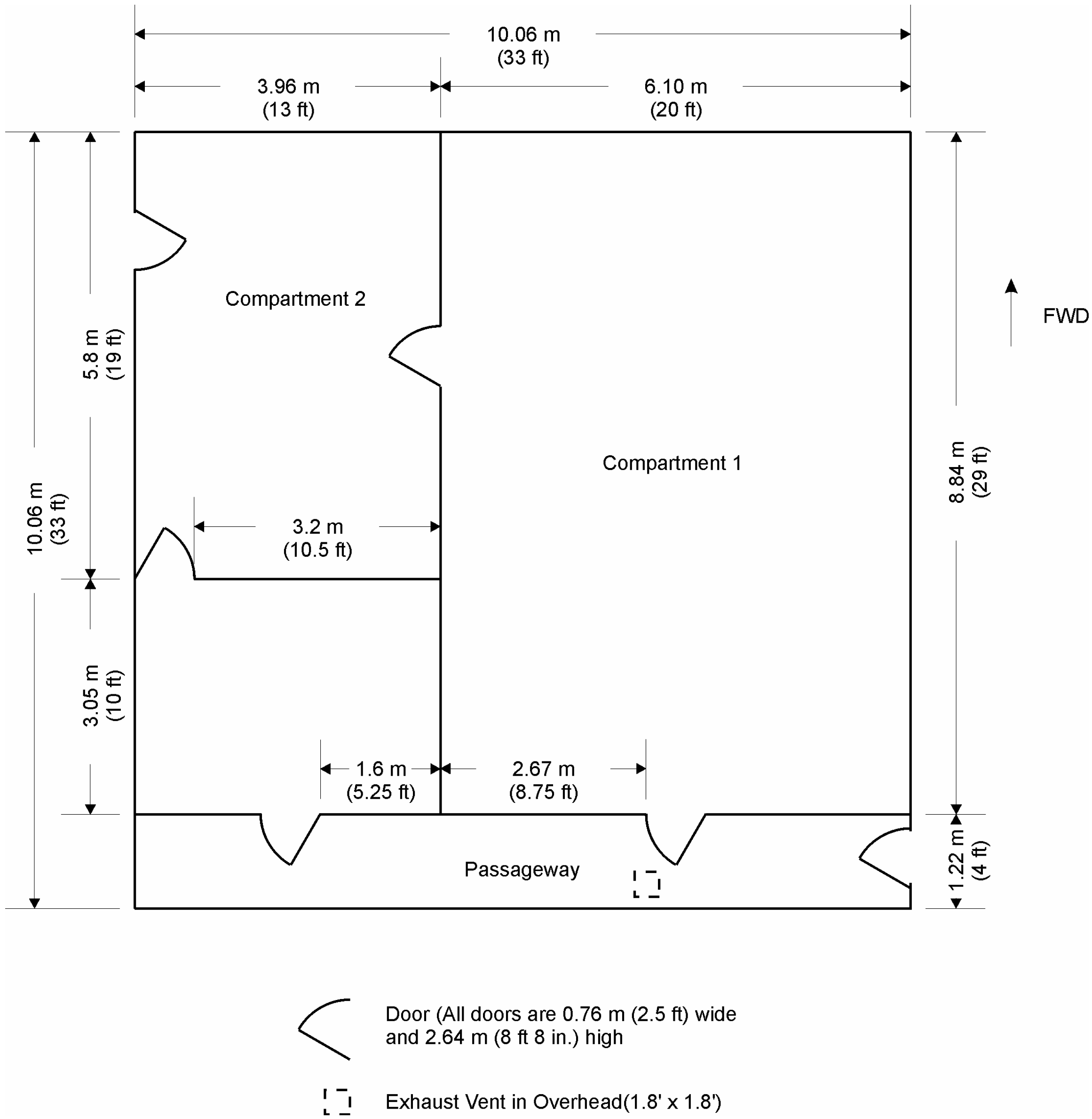

Fig. 1 — Compartment layout within test facility

Table 1 — Overall Dimensions of Test Compartments and Passageway

Test Space	Length (m (ft))	Width (m (ft))	Height (m (ft))
Compartment 1	5.9 (19.5)	8.8 (29.0)	3.0 (10.0)
Compartment 2	6.0 (19.8)	3.6 (11.8)	3.0 (10.0)
Passageway	10.0 (33.0)	1.2 (4.0)	3.0 (10.0)

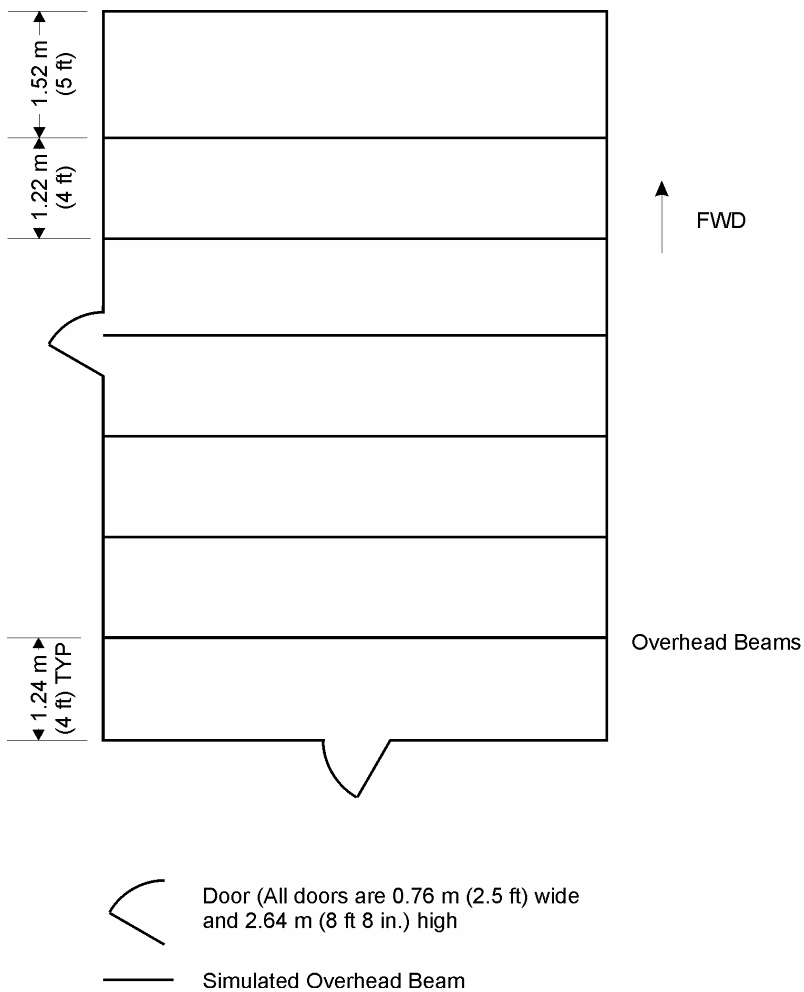

Fig. 2 — Simulated beam locations within Compartment 1

4.1 Lighting

Lighting on naval ships includes many forms of illumination that may affect video surveillance and detection. This includes general, detail, special, red, yellow, low level white, broadband blue, emergency and darkened ship illumination. Each form of lighting is specific to an event, location and purpose. General illumination includes all white light from fixtures on the overhead and bulkhead, except detail lighting fixtures. Detail illumination provides light for a specific task such as a desk lamp, while special illumination is the miscellaneous fixtures for purposes other than those covered by general and detail illumination. Red illumination minimizes interference with dark-adapted vision, and is used in compartments or passageways that connect directly to the outside of the ship. Providing red illumination helps to reduce night-vision adaptation. Low Level White (LLW) light is used in command and control spaces of submarines and some surface ships where color display consoles are used, while Broad Band Blue (BBB) illumination is used in command and control spaces where cathode ray tube display

consoles are used. Darkened ship conditions are established to ensure light security while

emergency illumination from lighting systems is designed to provide illumination during emergencies or conditions that interfere with normal lighting systems.

DoD-HDBK-289 Lighting on Naval Ships and NSTM chapter 330 Lighting provide the design criteria and applicable illumination levels for various ship compartments. The manual also contains terminology and lighting equations, as well as the design process for ensuring adequate illumination is available for the tasks to be completed in each compartment. Design requirements include specifics on the distribution system, type of illumination required, illumination levels, uniformity of illumination, brightness ratio and glare. The range of illumination levels (foot-candles) for specific compartment functions is shown in Table 2. The levels range from 3 to 42 foot-candles. The illumination levels, for the most part, are in increments of 7, ranging from 7 to 42 foot-candles, with a minimum illumination level of 3 foot candles.

Table 2 — Illumination Levels of Various Compartment Functions from Dod-HDBK-289 Lighting on Naval Ships

Function Group	**Hanger spaces**	**Living spaces**	**Damage control spaces**	**Electronic equipment spaces**	**Machinery Spaces**	**Ordnance Spaces**	**Medical spaces**
Illumination (Foot-candle)	7.0, 14.0	7.0, 14.0, 28.0	7.0, 14.0	14.0	7.0, 14.0, 21.0	3.0, 7.0, 14.0	28.0, 42.0

Lighting was installed in the overhead of the test compartments to provide illumination comparable to various spaces onboard naval ships, Figure 3. The lighting system was installed in general accordance to DoD-HDBK-289. In the test compartments, the lighting was suspended approximately 0.3 m (12 in) below the overhead, making them flush with the overhead beams. Commercial fluorescent light fixtures [Lithonia model number LB 2 20 120 LPF] were used. The lamp was a low profile wraparound fluorescent fixture with a lamp power rating of 20 Watts supplied with a voltage of 120 AC. The fixtures measured 7.6 cm (3 in.) in height, 61.0 cm (2 ft) long, and 25.4 cm (10 in.) wide. Two 20-Watt Fluorescent Bulbs [General Electric model number F20T12/CW] were used with each light fixture. To achieve the 14 Fc illumination level all 15 light fixtures were powered on. The illumination level was reduced to 7 Fc by disconnecting one of three circuits attached to the light fixtures. The circuit shut off four lights, the two light fixtures 1.83 m (6 ft) forward from the aft bulkhead and the two fixtures 2.13 m (7 ft) aft from the forward bulkhead achieving 7 Fc. To achieve the 28 Fc illumination level halogen lamps were attached to the overhead. The halogen lamps were positioned in the four corners of the compartment as well as the center of the port and starboard bulkheads. The halogen lamps provided an efficient means to achieve the adequate light level. The red illumination was accomplished by covering the fluorescent bulbs at the 14 Fc setup with colored sleeves [Arm-A-Lite Safety Sleeves model number TP312W/R/T12].

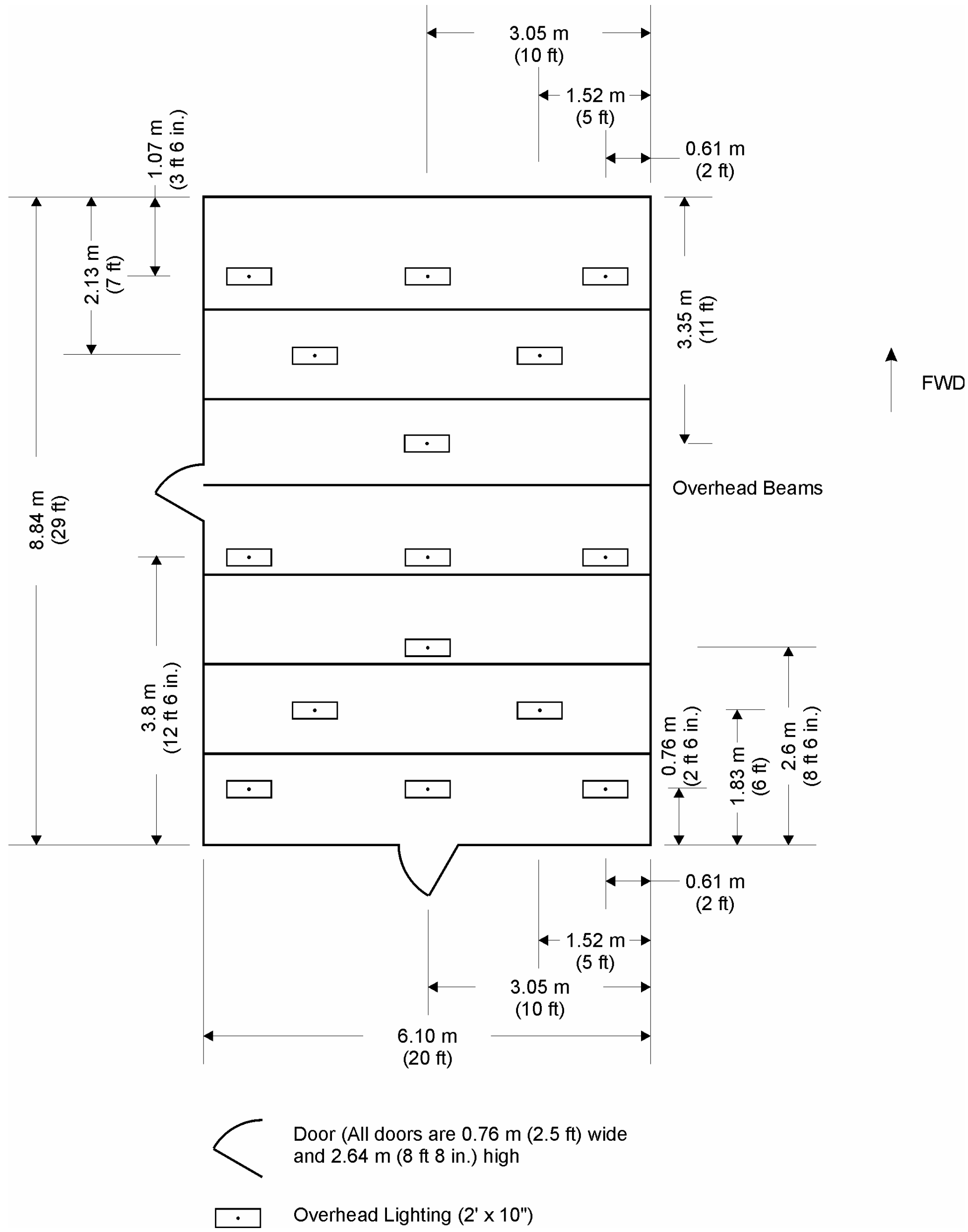

Fig. 3 — Light fixture layout in Compartment 1

Once the lighting system was complete, a photometric survey was conducted to ensure the uniformity and level of illumination at 0.76 m (30 in.) above the deck. A height of 0.76 m was used to comply with DOD-HDBK-289 section 4.1.3. The photometric survey used a light meter [Extech model number 401025]. The light meter was capable of measuring up to 5000 foot-candles (Fc) with a measuring resolution of 0.1 for the 0-200 Fc range used with a 180˚ viewing angle. Three illumination levels were systematically tested, 28.0 foot-candles, 7.0 foot-candles, and the most common illumination level of 14.0 foot-candles. To ensure adequate and uniform illumination levels a procedure was devised for mapping the illumination level. The photometer was mounted on a tripod to ensure that a height of 0.76 m was maintained. The tripod also isolated the light meter from cabinets or users that could obstruct light from entering the photometer. The deck of the compartment and passageway were divided into two-foot squares and the stand was moved through each square to map the illumination level. A pattern was

created over the entire deck of the test space to ensure a total surface map of the illumination levels was created. The illumination level at the calculated 14 Fc level had an initial value of 12.2 +/- 2.0 Fc. Figure 4 shows the light level mapping for the 14 Fc illumination level. Additional light level maps are included in Appendix A.

A decrease in the illumination level was observed over the duration of the testing. This slight decrease in illumination level can occur do to aging of the fluorescent light bulbs. It was noted that once the bulbs have aged 100 hours a decrease in illumination level of 10% to 15% is expected by the manufacturer. In addition smoke deposits (i.e., soot) was observably collecting on the outside glass and plastic covers of the light bulbs, thus, decreasing the illumination levels over time. In an attempt to maintain the illumination levels relatively constant, the bulbs were periodically cleaned. In addition soot deposits on the light fixtures, deck, overhead, and bulkheads would also reduce the illumination level within the compartment. At the end of testing, photometric surveys were performed to measure the illumination levels within Compartment 1. Without cleaning the soot from the fluorescent bulbs, the survey produced an illumination level of 6.7 +/ - 0.9 Fc. After cleaning the light bulbs an illumination level of 8.9 +/ - 1.2 Fc was recorded. It should also be noted that the photometric surveys were conducted in an open space without any obstructions in the compartment. The introduction of obstructions significantly changes the illumination map creating areas of lower illumination levels (shadows). As a result of the changing conditions within the compartment, including soot deposits, obstruction placement and source location, it should be noted that the illumination levels studied and reported are maximum values that serve to provide a relative range of realistic shipboard conditions.

In addition to the changes in illumination and camera settings, different colored bulkheads were evaluated to analyze the video systems performance to various background colors typical of naval ships. Based on ship visits and design specifications, two colors were selected to provide a range of conditions. The test spaces were painted a standard Navy ship interior color of white and gray. The colors were matched by Sherwin-Williams to be indistinguishable by the naked eye to DOD-E-24607A chlorinated alkyd enamel paint color white (FED-STD-595 color No. 27880) and bulkhead gray (FED-STD-595 color No. 26307). The forward and port bulkheads were painted gray while the aft and starboard bulkheads in Compartment 1 were painted white, Figure 5.

4.2 Obstructions

In addition to the overhead “beams” and light fixtures in Compartment 1, obstructions in the form of tables, chairs, and electrical cabinets were placed within Compartment 1. This obscured the view of the video cameras providing a challenge to the video detection systems. The cabinets were approximately 1.83 m (6 ft) in height and dispersed throughout the compartment as shown in Figure 6 for the first tests conducted. The obstructions were configured into two separate layouts, Figure 6 and Figure 7. In the second layout, the obstructions were placed to represent a working compartment and to provide a symmetric geometry. In Figure 7, the electrical cabinets were symmetrically placed in such a way that the two cameras in Location 1 and Location 4, across from one another, had similar images in front of the different colored bulkheads. The cabinet configuration was changed from layout 1 to the symmetric layout 2 for test number 91 and stayed that way for the remainder of testing.

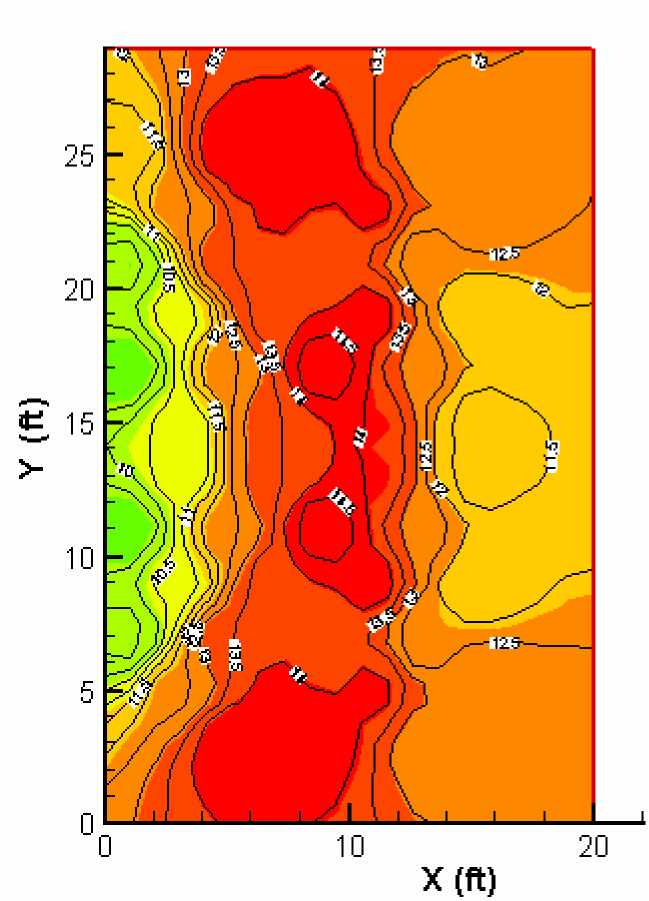

Fig. 4 — A map of the illumination level at a plane 0.76 m (30 in.) above the deck for the calculated level of 14 Fc Compartment Color

Fig. 5 — Image of intersecting bulkheads, one white one gray

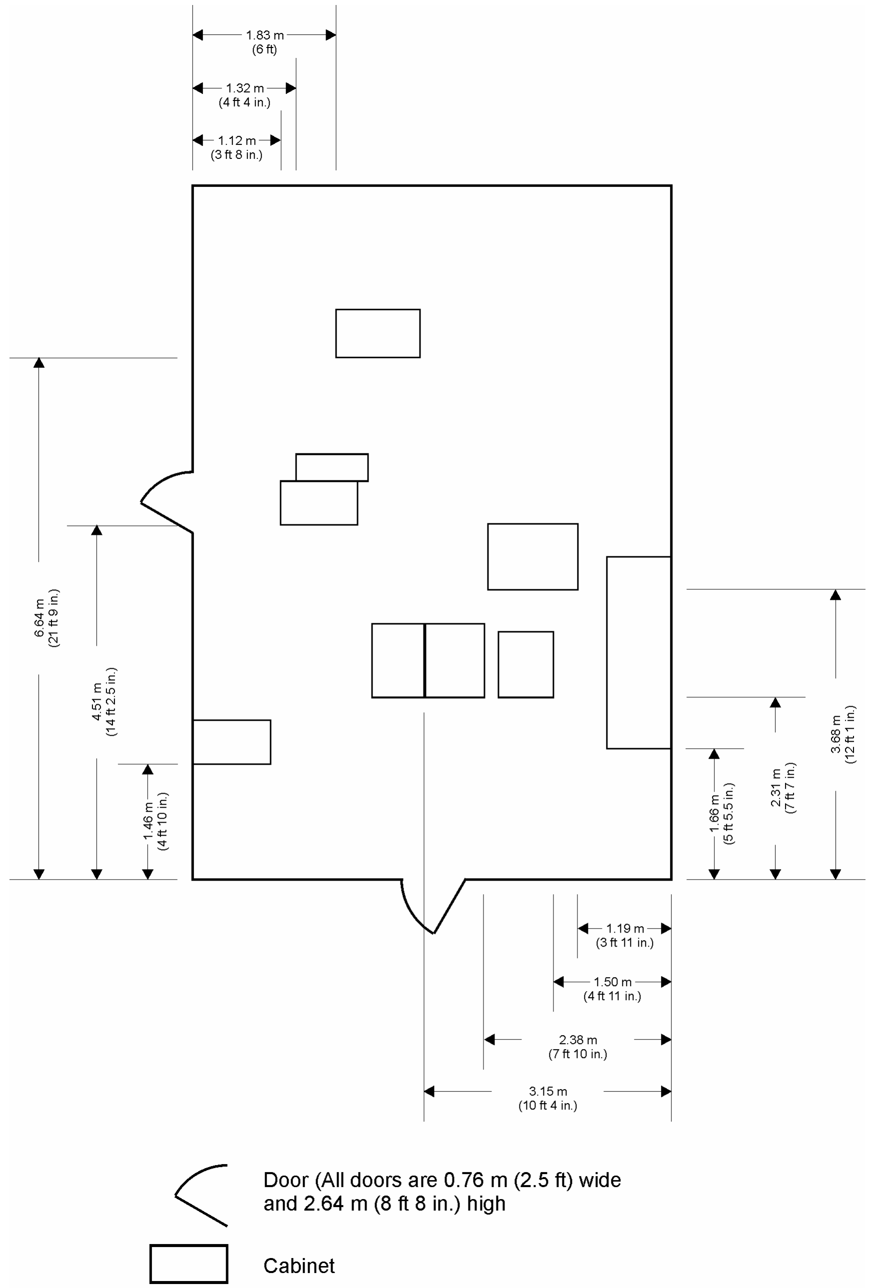

Fig. 6 — Original layout of obstructions in Compartment 1

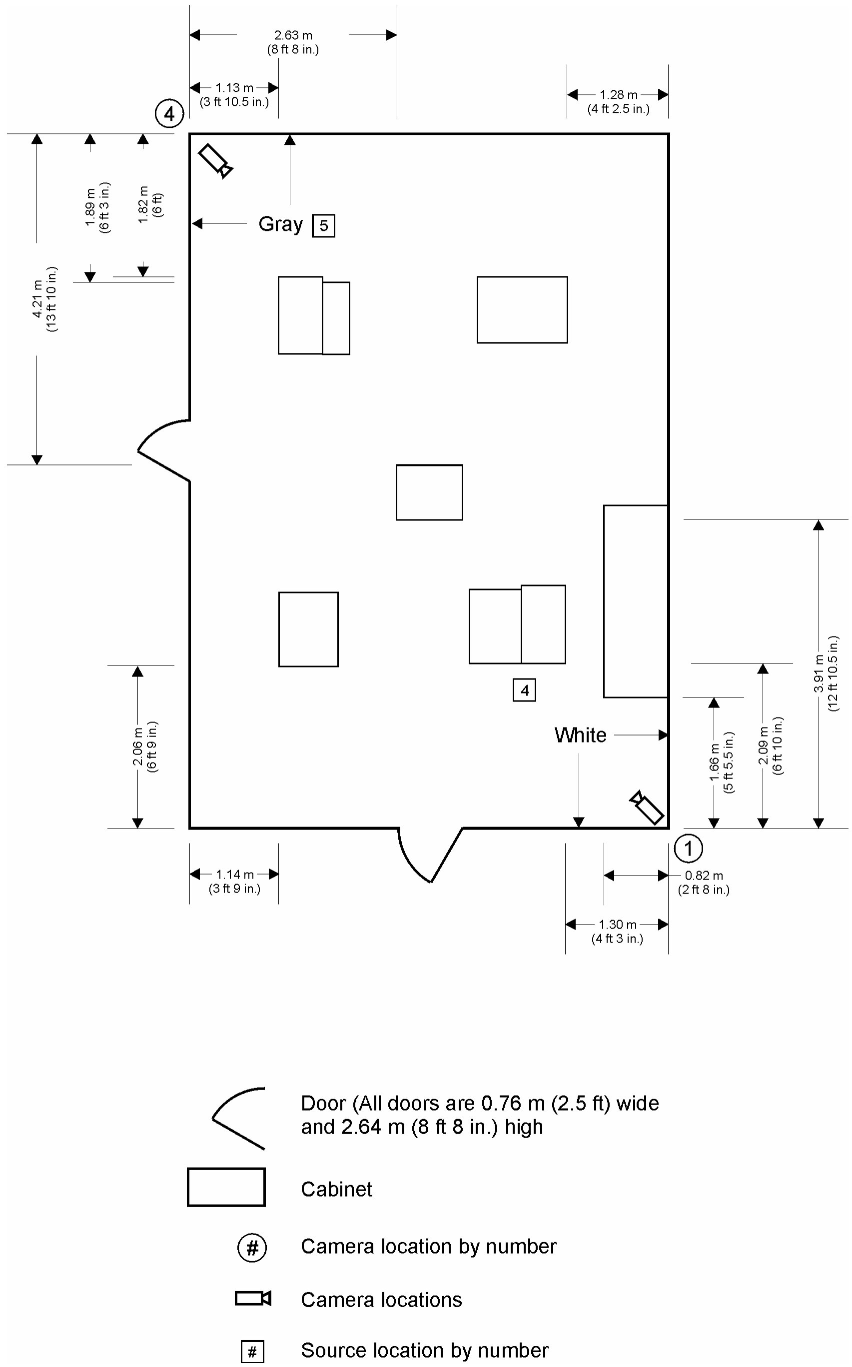

Fig. 7 — Symmetrical layout of obstructions placed in Compartment 1

Obstructions in the passageway consisted of ductwork, light fixtures, and a cable tray in the overhead. Figure 8 presents an image of the overhead in the passageway. A single cable tray, 4.57 m (15 ft) long, was suspended down the center of the passageway 30 cm (1 ft) below the overhead. The cable tray was centered lengthwise in the passageway. On top of the tray two sections of 19 cm (7.5 in.) diameter steel duct, 1.4 m (4.5 ft) long, were laid perpendicular to the cable tray. Figure 9 shows a diagram of the passageway layout.

Fig. 8 — Image of the overhead obstructions in the passageway looking port

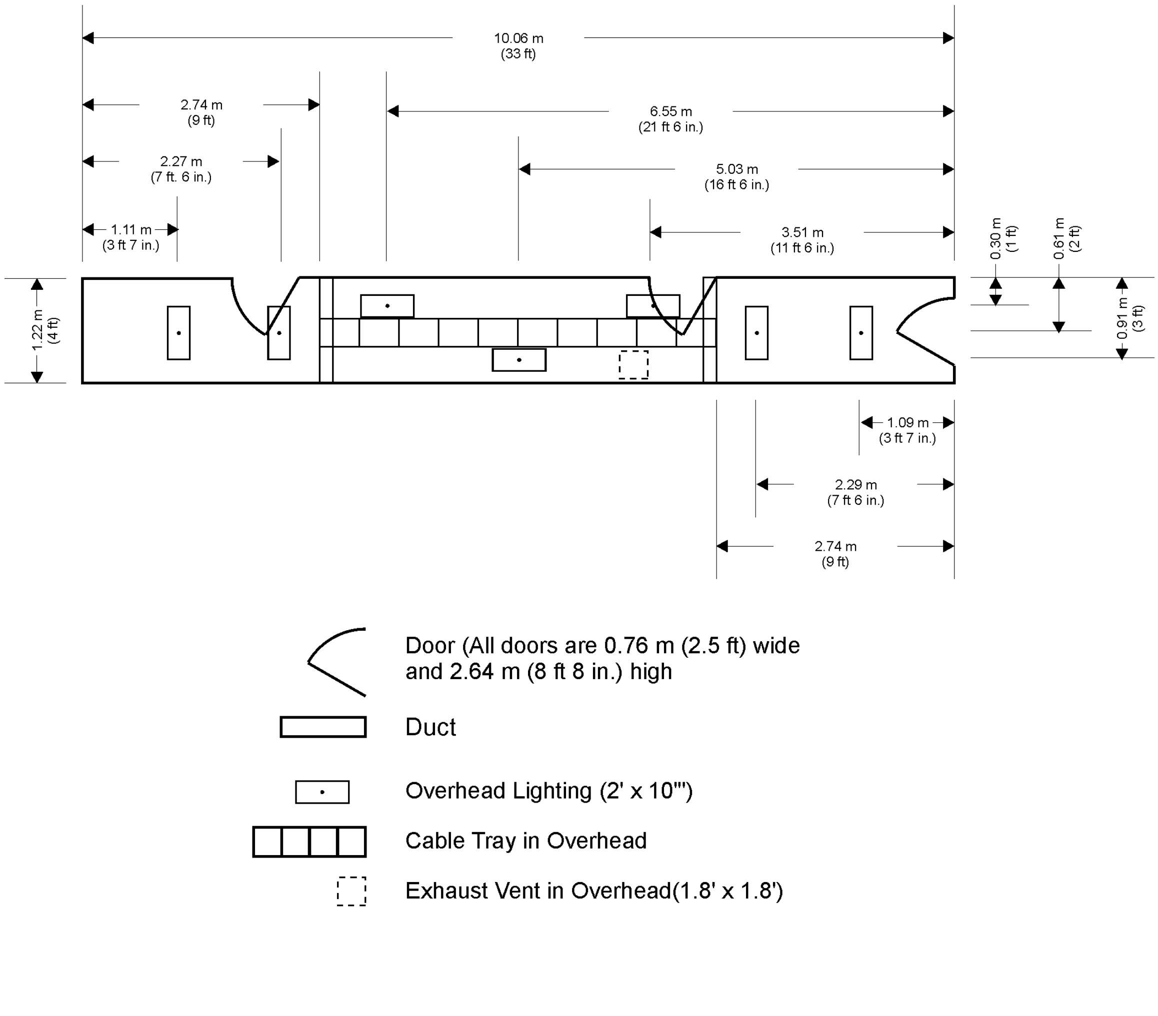

Fig. 9 — Layout of obstructions in the passageway overhead

4.3 Instrumentation

Besides commercial fire alarm equipment, instrumentation was installed throughout the test compartments to measure temperature, carbon monoxide and smoke density (visibility). Video recordings of the camera image as well as still photos were taken to monitor and document the conditions within the test compartment.

Table 3 lists all of the fire detection systems evaluated in this test series as well as other sensors being investigated as part of the volume sensor program. The table includes the type of detection technology and specific model numbers for each device. Additional details of the detection systems are given in Sections 4.3.1 through 4.3.5. Figure 10 and Figure 11 show the locations of the detectors within Compartment 1 (Bay 3 and Bay 5 relative to the forward bulkhead) and the passageway, respectively.

The detector types and their respective locations in each test compartment were chosen to allow the response of the different detection methods to be compared based upon complete systems with full space coverage. The smoke detectors were installed to industry standards (i.e., NFPA 72 [13]).

Camera locations can be seen in Figure 12 and Figure 13 for Compartment 1 and the passageway. The camera views do not necessarily represent the optimum placement. Rather, the cameras were setup to provide a range of views that also cover the entire test area, while taking into account the possible clutter in the space, such as overhead cables, ventilation ductwork, light fixtures, and beams. The optimum number of cameras and placement were evaluated by assessing the performance of different groupings of cameras within the spaces.

Table 3 — Fire Detection Equipment and Sensors

Manufacturer	**Model and/or Number**	**Description**
Fire Sentry	VSD-8	Video smoke detection system
Fastcom	Smoke & Fire Alert (SFA)	Video flame and smoke detection system
AxonX	SigniFire	Video flame and smoke detection system
Edward System Technologies (EST)	SIGA-IPHS SIGA-IS SIGA-PS	Multi-Sensor Detector Ionization Smoke Detector Photoelectric Smoke Detector
Notifier	SDX-751 FSI-751	Photoelectric smoke detector Ionization smoke detector
Spectral-Based Volume Sensor Test bed		
Vibrometer	Omniguard 860	UV/IR OFD
Sensor Electronics	EyeSpy 502-09	UV/IR/BB OFD
UDT Sensors	UV100	Si Photodiodes with IF (mx, 5900, 7665, 10500 A)
Judson Technologies	J14TO Series, Model PE-0-51	4.3 micron RT IR
Hamamatsu	R446	PMT with 2600 A IF
Hamamatsu	R446	PMT with 3070 A IF
Long Wavelength Cameras		
CSi-SPECO (0.02 Lux)	CVC-130R	B/W Bullet camera with IF (LP or SP)
Sony (0 Lux)	DCR-TRV 27 or DCR-PC-101	Color camcorder with IF (LP or SP)
NRL	LWVD System	NRL prototype Machine Vision Event Detection System, available for test VS2-95 and above
Lorex	VQ-2120	8500 A NIR Illuminator
UV/VIS Spectrometer		
Ocean Optics	HR2000	UV/VIS Fiber Spectrometer
Acoustic Sensors		
Bruel & Kjaer	4141	Extended-range microphone (3-40000 Hz)
Shure	KSM 141	Standard microphone (20-20000 Hz)

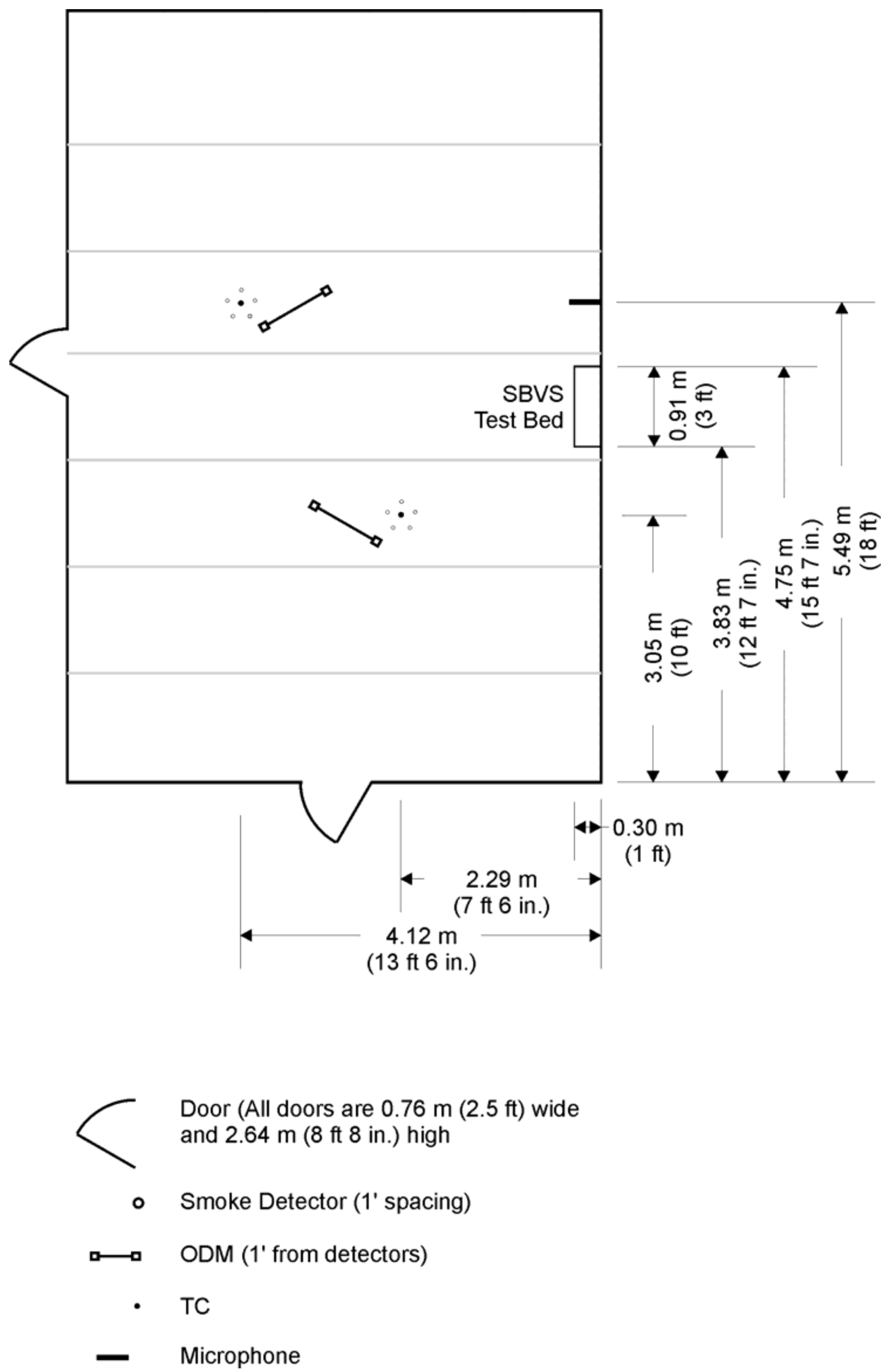

Fig. 10 — Location of detectors and instrumentation within Compartment 1

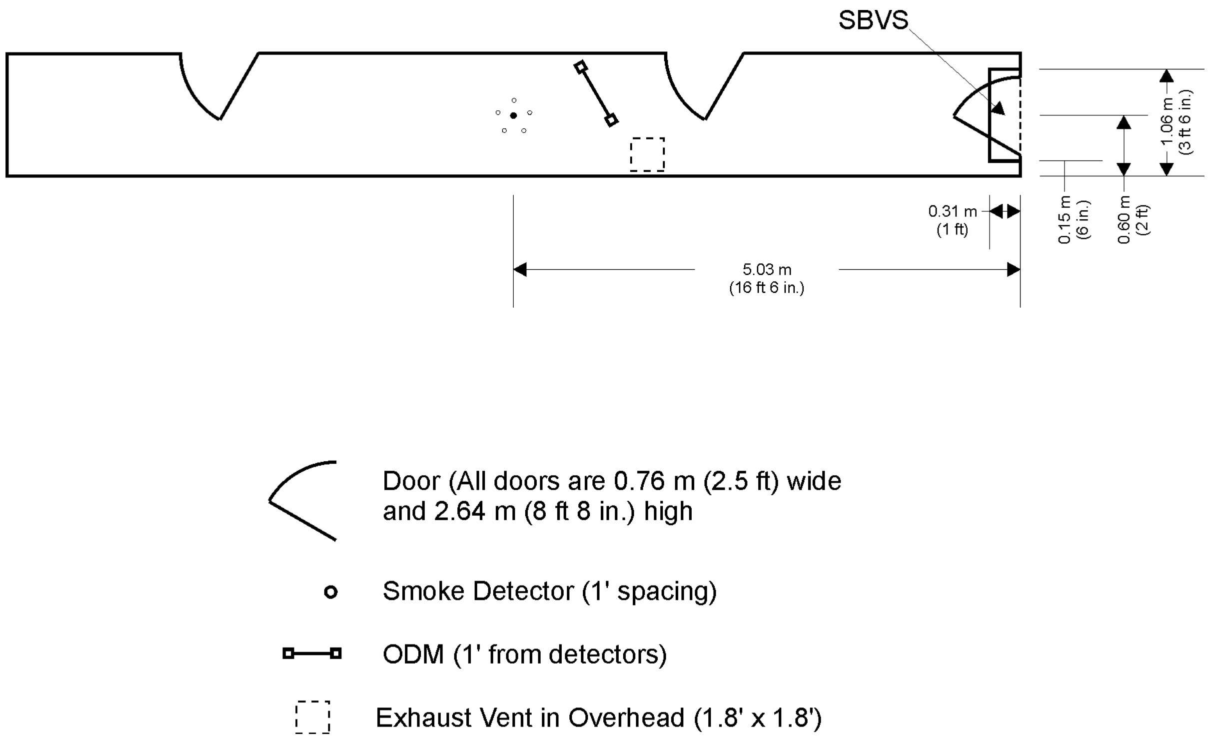

Fig. 11 — Location of detectors and instrumentation within the passageway

4.3.1 Thermocouples

Thermocouples (TCs) were used to monitor air temperatures. Type K, 24 gauge bare bead thermocouples were used to measure the overhead gas temperatures at the detectors. The thermocouples were positioned at the approximate height of the detector heads 8 cm (3 inches) below the overhead. In addition one TC was placed at 1.5 m (5 ft) above the deck in the center of the space to measure the air temperature for tenability purposes.

4.3.2 Optical Density Meters (ODM)

Optical Density Meters (ODMs) were mounted to the overhead in Compartment 1, in Bay 3 and Bay 5, and in the passageway to monitor smoke development. The ODMs had a 1.5 m (5.0 ft) path length and were positioned adjacent to each grouping of smoke detectors, such that the white light beam was 10 cm (4 in.) below the overhead. The white light ODM consisted of a spot light and a photocell consistent with the specifications in UL 217, Standard for Single and Multiple Station Smoke Alarms [14]. ODMs were installed in Compartment 1 and the passageway as shown in Figures 10 and 11, respectively. In addition one ODM was placed in the center of Compartment 1 at 1.5 m (5 ft) above the deck to measure the visibility at head height for tenability purposes.

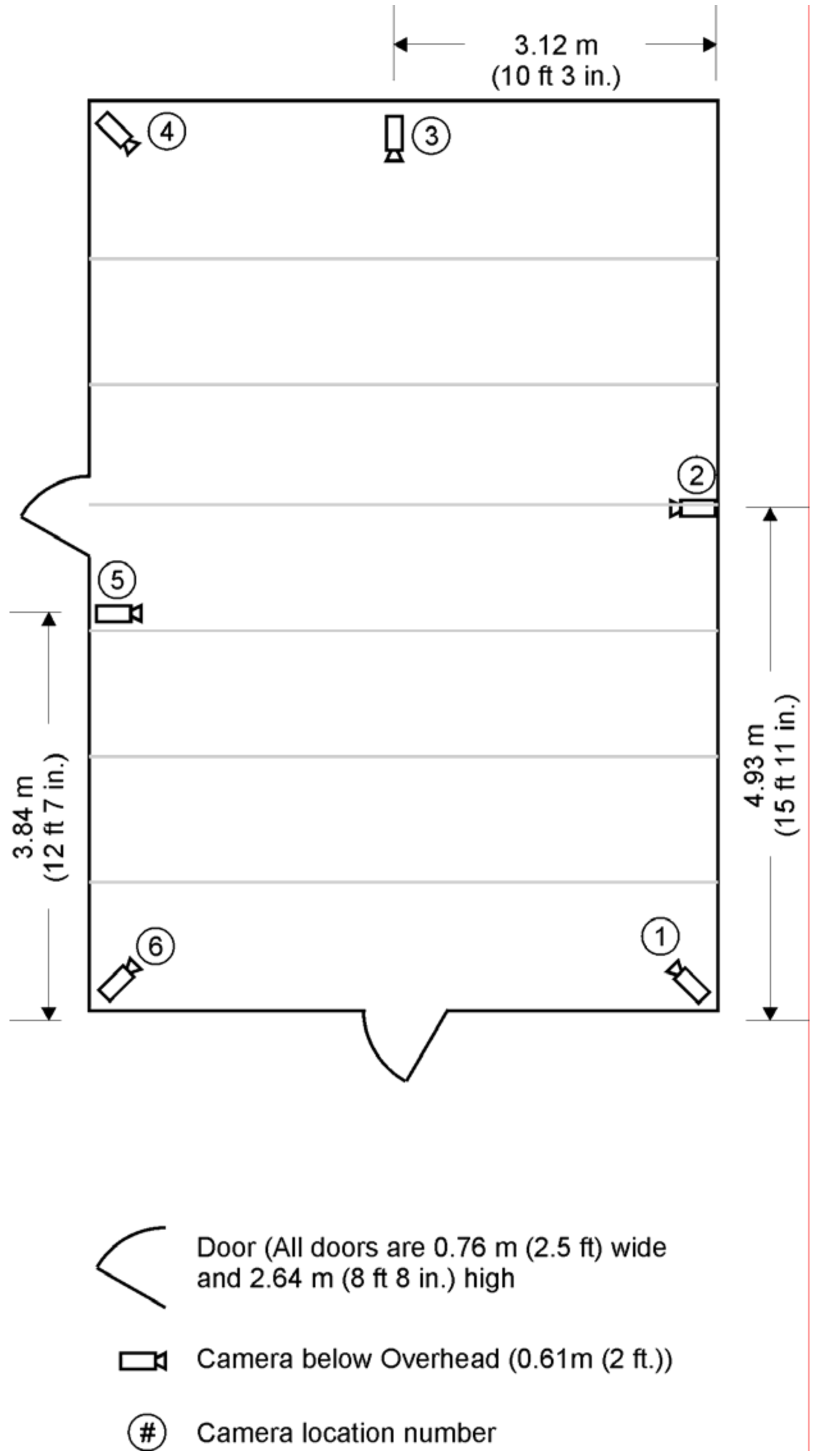

Fig. 12 — Camera locations within Compartment 1

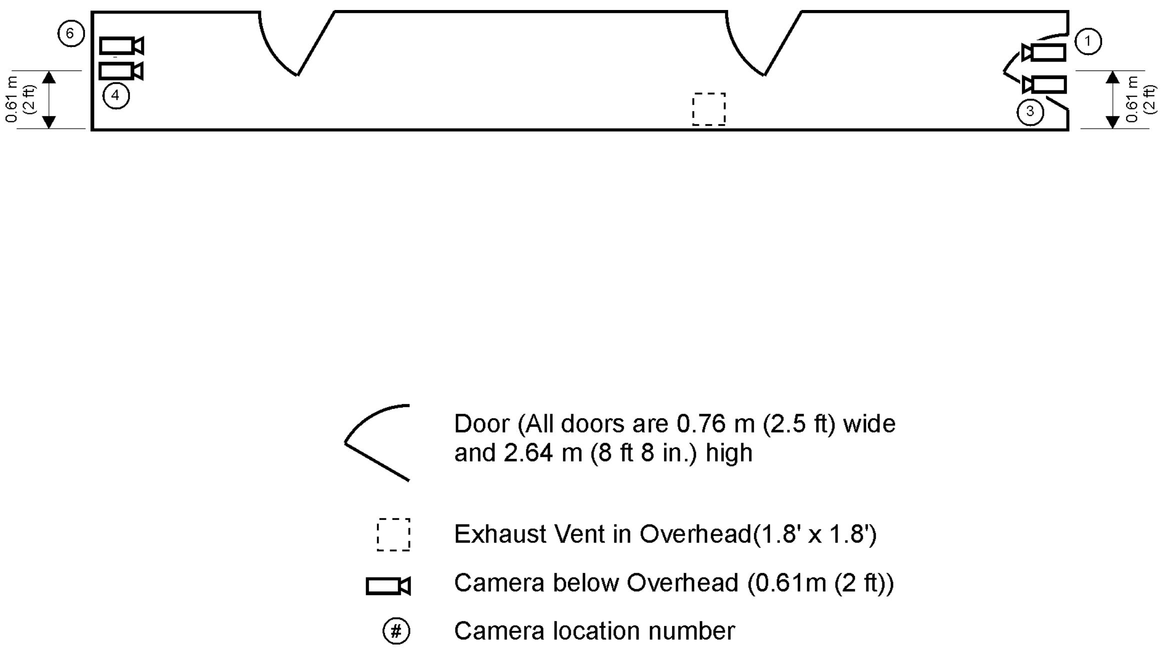

Fig. 13 — Camera locations within the passageway

4.3.3 Video

Standard, security-type video cameras were installed to monitor and record each test and the conditions in the test space. These video cameras were the same cameras used with the VID systems. The video images were obtained using one of two models of standard CCD color cameras, Sony SSC-DC14 and Sony SSC-DC393 with Pentex manual iris 3.5 to 8 mm, variable focus lens. The SSC-DC14 cameras were the same camera model used in the FY02 work. Two SSC-DC393 cameras were purchased for this test series because the SSC-DC14 units were no longer available and the SSC-DC393 cameras, per the manufacturer, were the replacement models for the older units. Table 4 lists the camera capabilities for each camera for comparison purposes. A notable difference in the camera models is the feature that produced a white image when the compartment was under red illumination conditions.

Table 4 — Camera Capabilities for the Sony SSC-DC14 (Older Model) and SSC-DC393 (Newer Model) CCTV cameras

Camera Capabilities	Sony SSC-DC14	Sony SSC-DC393
High resolution and high sensitivity with a 1/3 type Exwave Hole Accumulated Diode (HAD) CCD and 1/3 type Super HAD CCD as the imaging device	NO	YES
CCD-Iris function	YES	YES
Automatic white balance tracking and adjustment	YES	YES
Compatible with DC controlled or video signal controlled auto iris lenses	YES	YES
Automatic backlight compensation and automatic flicker reduction through Smart Control	YES	NO
BLC Backlight Compensation through the center measurement	NO	YES
LEVEL adjustment for various lighting conditions	NO	YES
Line lock function for synchronizing through AC power source	YES	NO
AC line lock and INT	NO	YES
Power Supply: Automatically switches between DC 12 V and AC 24 V	NO	YES

The video cameras have a number of adjustments and features that affect the picture quality. In most cases, the settings are adjusted to give the clearest picture to the viewer. However, this can result in a qualitative judgment of image quality. Optimal camera settings were determined based on visual observation of the video image as well as by image metrics provided by the VID systems. The SFA system provided an image quality value indicating whether the image is optimum, very good, good, ok or poor. The SigniFire system provided a histogram that can be used with internal adjustments for the brightness and contrast. Even though the SigniFire system accepts color images, it does not use the color and treats the images as black and white. The x axis of the histogram is a brightness parameter, while the y-axis is the normalized frequency (max=1), or number of pixels in the image that have a particular brightness. If the entire image is black, the histogram will be like a delta-function (spike) at x equal zero, if the image is white, the delta-function will be at a maximum (x=255), and if the image is all gray, it will be somewhere in the middle. Maximizing the area under the curve equates to an optimal image. VSD-8 provides on screen warnings indicating areas of low or high contrast. To optimize the cameras for the VID systems, adjustments were made to the contrast and focus settings of the cameras. The camera settings were systematically adjusted until the VSD-8 poor contrast indicators were eliminated and while the SFA quality values were maximized. Once the best image was captured based on user perception, SFA image quality value, and VSD-8 indicators, internal adjustments were made to the SigniFire system to maximize the area under the histogram. This procedure for optimizing the camera setting was repeated throughout testing. Figure 14 shows the image of each of the 6 optimized cameras when collocated to have the same field of view. Over the duration of the test program, it was noted that the camera image quality decreased based on the SFA system image quality indicator and user observations. This decrease in image quality is believed to be due to the

repeated exposures to fire gasses. The cameras were sent back to the manufacturer for refurbishment after test number 253.

Fig. 14 — Optimum Camera images for Cameras 1 through 6 collocated at Location 1

During several sets of tests (see Section 5) with collocated cameras, the effects of variations in camera setting were evaluated. The focus and contrast of the cameras were adjusted to provide video images that were not optimal, yet still within tolerable conditions. In other words, the focus and contrast were adjusted to represent off-optimal conditions that would not dictate immediate correction; that is, ship personnel using the equipment would recognize that the image was not perfect but may not feel compelled to make adjustments. The two primary settings affecting the picture quality are the focus and the iris. The iris controls the amount of light into the camera. It is used to maximize and sharpen the division between dark and light objects (i.e., the contrast). If the iris is closed too far, the contrast may be very dark with loss of detail in parts of the image. If the iris is opened too far, the contrast decreases causing the image to become over exposed. These two settings were systematically adjusted to produce varying conditions and to identify the optimum settings for detection for each of the VID systems. These tests incorporated a high, low, and optimum contrast as well as "out" of focus for a combination of four scenarios to be tested with various flaming and smoldering sources, Figure 15. In addition, the older and newer model Sony cameras were compared to determine performance differences.

In addition to the standard video cameras, nightvision cameras (bullet cameras with filters attached, such as a Long Pass (LP) 720, or LP 850 or Short Pass (SP) SP690 filter) were used. These setups captured a near infrared Near Infrared (NIR) image that provided moderate thermal imaging for the Long Wavelength Video Detection (LWVD) system discussed in Section 4.3.6. These cameras were collocated next to the other Sony video cameras with one or two cameras installed at Locations 1 and 4 in Compartment 1, see Figure 12. The cameras were also used in

the passageway, located on the starboard end above the door, see Figure 13. The signal from the nightvision cameras was sent to the commercial VID systems for alarm processing, as well as to the (LWVD) system.

Fig. 15 — Images of the various camera settings at Location 1 (Camera 1 = optimized, Camera 2 = light contrast, Camera 3 = dark contrast, Camera 4 = out of focus, Camera 5 = optimized (new), and Camera 6 = dark contrast (new))

4.3.4 Spot -Type Smoke Detectors

Two commercial smoke detection systems were used to provide a benchmark of state-of-the-art, spot-type fire alarm equipment performance. The Edward System Technologies (EST) system detectors were monitored using a single EST3 alarm panel interfaced via the EST program Firemark. The panel was configured by the manufacturer to standard recommendations. The EST detector response times were evaluated at the manufacturer's default alarm sensitivity levels, which were the least sensitive settings. As shown in Table 5, these settings were 11.0%/m (3.5%/ft) for the photoelectric units and 5.1%/m (1.6%/ft) for the ionization units.

Table 5 — EST Alarm Sensitivity Settings in % Obscuration/m (%/ft)

Detector	**Model**	**Alarm Level** (% obscuration/m (%/ft))
Photoelectric	SIGA-PS	11.0% (3.5%)
Ionization	SIGA-IS	5.1% (1.6%)

The Notifier system detectors were controlled using an AFP 400 panel. The panel was configured using the Notifier Veri•Fire 400^{TM} Programming Utility, which allows programs to be edited, downloaded and uploaded from a personal computer. A manufacturer modified version of the panel software was utilized to allow the history file to record event times to the nearest second (typical panel operation only records times to the nearest minute). The Notifier panel recorded alarm responses for "pre-alarm" and "alarm" sensitivity levels. These levels were preset with the software to one of nine selectable values corresponding to the specific range of each detector type. Table 6 presents the alarm levels used for the Notifier smoke detectors.

Table 6 — Notifier Alarm Sensitivity Settings in % Obscuration/m (%/ft)

Detector	**Model**	**Pre-Alarm Level (% obscuration/m (%/ft))**	**Alarm Level (% obscuration/m (%/ft))**
Photoelectric	SDX-751	4.26 % (1.33 %)	6.76 % (2.12 %)
Ionization	FSI-751	4.02 % (1.25 %)	5.62 % (1.75 %)

Each spot-type detector was mounted to a standard electrical box that was then mounted directly to the overhead. The openings to the detectors were approximately 0.13 m (5 in.) below the ceiling. The detectors were spaced 0.3 m (1.0 ft) center to center within each grouping. Figures 10 and 11 show the location of the detectors within Compartment 1 and the passageway, respectively.

4.3.5 Video Image Fire Detection Systems

Three commercially available video image detection (VID) systems were evaluated. Each system was operated from an independent personal computer (PC). The Smoke and Fire Alert (SFA) system was installed on a standard Gateway© Pentium 4 PC running Microsoft Windows XP. The SFA system utilized both flame and smoke alarm algorithms to detect fires. The manufacturer uses the term "Fire" alarm to indicate a flame. The VSD-8 system came installed on a proprietary PC running Microsoft DOS. The VSD-8 used only a smoke alarm algorithm for detection. The SigniFire system was installed on a standard PC running Microsoft Windows 2000 and was later replaced with a manufacturer-supplied rack-mount unit running Microsoft Windows XP Home. This system consisted of two flame algorithms and a smoke alarm algorithm. For the first 47 tests, the SigniFire smoke alarm algorithm was not functional as a new version was being finalized. The flame algorithms consisted of one for fires directly in the field of view of the camera and a second algorithm to detect fires outside the field of view. The later algorithm is referred to by the manufacturer as an offsite alarm.

All three of the VID systems used the same cameras located in the test spaces. The VSD-8, SigniFire and SFA systems were all designed for up to 8 video inputs. Using a Siamese cable (RG59 coax for video together with 18/2 for power), each video image was transmitted to an electronic distribution amplifier [Kramer Electronics, 105VB], which split the signal to four destinations: 1) the SFA video detection system, 2) the VSD-8 video detection system, 3) the SigniFire video detection system, and 4) a VCR or digital recorder, preceded by a time-date generator.

All video image fire detection systems included hardware and software to provide analog outputs corresponding to alarm conditions. Alarms for these systems were indicated by a step change in the corresponding output value for each camera. Due to equipment problems, the VSD-8 system was unable to provide individual outputs for each camera until Test 104. Therefore, some of the evaluations presented in this report do not include results for the VSD-8 system since specific camera responses could not be discerned.

Each VID system maintained an electronic history file of all alarms, including a digital photo (VSD-8 and SFA) or movie (SigniFire) showing the video image that caused the alarm condition for each entry. This allowed for a review of each alarm to assure that the event was due to fire or smoke and not from an unintended source, such as participants moving around inside the compartment during a test. The SFA and SigniFire systems provided for each historical image and movie, respectively, the time and date of the event, the alarm type, camera identification and file name. The SFA-8 historical image displays the date and time of alarm, but it does not indicate the camera number.

4.3.6 Long Wavelength Video Detection and Analysis

As noted in Section 4.3.3, long wavelength video was provided by nightvision cameras collocated with the Sony video cameras in the compartment and passageway setups. The long wavelength, or nightvision, cameras were bullet cameras with LP or SP filters. The LP filters transmitted incoming wavelengths above the specified cutoff wavelength, which suppresses the visible image and generates a high contrast video image dominated by long wavelength, near IR emission. The SP filter was used to generate a normal contrast black-and-white image for direct comparison to a nightvision camera image in a small number of tests. The nightvision cameras were installed before test 49, which was midway through Test Set 4.

The video output signal from the nightvision cameras was split and sent to the three commercial VID systems for analysis. In addition, the signal was sent to a simple luminosity-based algorithm developed at NRL for analysis of nightvision images. The luminosity algorithm was designed to capture the enhanced sensitivity of the nightvision cameras to the thermal emission of fires, hot objects, and especially flame emission reflected off walls and around obstructions from a source fire not in the field of view of the camera, thereby augmenting the event detection and discrimination capabilities of the commercial VID systems. This goal was achieved by tracking changes in the overall brightness of the video image. Further details of the luminosity algorithm are available in reference [7].

To implement the luminosity algorithm, a prototype video image detection system was developed at NRL for use with the nightvision cameras. Further details of the prototype NRL LWVD video system are available in reference [7]. For this VS2 Test Series, the signal from a nightvision camera was converted from analog to digital video (DV) format with a Firewire video adapter (Dazzle Hollywood DV Bridge) or to digital AVI format with a USB video adapter

(Belkin USB VideoBus II), for suitable input into a computer. A program coded in Mathworks' numerical analysis software suite, Matlab v6.5 (Release 13), controlled the acquisition of video input from the cameras and performed analysis of the video images. Alarms

were indicated in real time and alarm times were recorded to files for later retrieval and compilation into a database. A background video image was stored at the start of each test. The alarm video image was stored when an alarm occurred along with the luminosity time series data for the entire test.

4.3.7 NRL SBVS Test Bed

The overall concept of the Volume Sensor and the experimental details of the Spectral-Based Volume Sensor (SBVS) Test bed have been briefly outlined in earlier sections of this document and discussed in greater detail elsewhere [6, 7, 8, 9]. The SBVS Test bed is composed of several optical detectors that operate in discrete portions of the electromagnetic spectrum, generally outside the visible region. The goal is to use spectrally rather than spatially resolved information to provide both detection and classification information not generally available to the standard video cameras and VID systems . This additional information would then be used to augment the performance of the VID systems, perhaps in conjunction with the enhanced spectral range of the long wavelength response cameras and VID algorithm of the NRL LWVD system [7].

The SBVS Test bed approach with single element sensors is to detect atomic, molecular and broadband emissions that are characteristically produced by flames. Typical flame emission spectra can be found in the literature and in Reference [8]. The technique is essentially an extension of the approach employed in commercially available optical flame detectors (OFDs), which typically include several elements operating in the IR or UV. The Test bed consists of two commercial off the shelf (COTS) OFDs with IR and UV detectors as well as in-house detectors at various wavelengths ranging from the mid IR to the UV. The OFDs (Sensor Electronics Eyespy 502-09 and Vibrometer OmniGuard 860) have been modified so that the outputs of each individual sensor element can be monitored and recorded independently in addition to the alarm status. The sensors that were configured in-house are intended to provide some redundancy with the commercial systems (IR at 4.3 μm and UV at 260 nm) as well as to explore the prospects of monitoring emission wavelengths not commonly used for flame detection. These sensor elements consist of a narrowband interference filter (typically 10 nm FWHM) placed in front of an appropriate detector, for example, a photodiode for the NIR or visible region and a photomultiplier tube (PMT) in the UV.

The SBVS test bed was installed on a shelf in each test compartment. In Compartment 1, the SBVS test bed was located on the starboard bulkhead 0.8 m (2.6 ft) below the overhead, 3.9 m (12.8 ft) from the aft bulkhead, see Figure 10. In the passageway, the SBVS test bed was positioned above the door 2.1 m (7 ft) above the deck, centered on the starboard bulkhead. The instrumentation on the SBVS test bed is identified in Table 3.

4.3.8 Acoustic Recording System

Two microphones were setup in the test compartment to monitor the acoustic emissions. An extended range microphone was placed near the source to measure the acoustic signature, while a second microphone was placed near the SBVS test bed to measure the signal arriving at a volume sensor system station.

The acoustic monitoring system was composed of one extended-range Brüel & Kjær microphone (3-40,000 Hz) and a standard microphone (e.g., 20-20,000 Hz), with conditioning amplifiers, a Sony DAT recorder, and a lunchbox Prism PC. Figure 16 shows a schematic of the

equipment used. The general purpose Shure KSM-141 microphone was fixed in place to monitor the test area. The Shure KSM-141 microphone was 5.334 m (17.5 ft) from the aft bulkhead and 0.43 m (1ft 5 in.) down from the overhead on the starboard bulkhead. The B&K 4141 extended range microphone was mounted on a tripod and pointed at the source from a distance of 1 m (3 ft 3 in.) Each of these microphones was powered by an amplifier. These amplifiers provided gain, and DC power to the microphone: in the case of the Shure unit, this was 48 volts and for the B&K unit it was 400 volts. The output from each microphone was wired to the inputs of the Sony instrumentation recorder and the data acquisition card in the Prism computer. The speakers were used for monitoring the signals out of the Sony recorder.

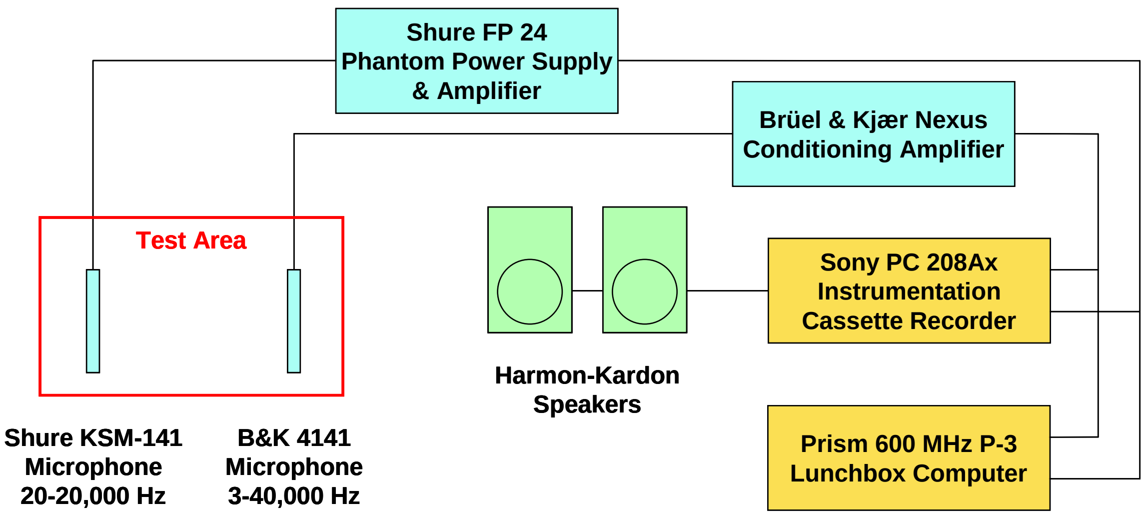

Fig. 16 — Acoustic equipment configuration

4.4 Source Exposures

Fire and nuisance sources were created to expose the detection systems to a range of scenarios. Fairly small fires were used to challenge the detection systems and to provide performance results for early detection. The sources were located throughout the test space as shown in Figure 17, Figure 18 and Table 7.

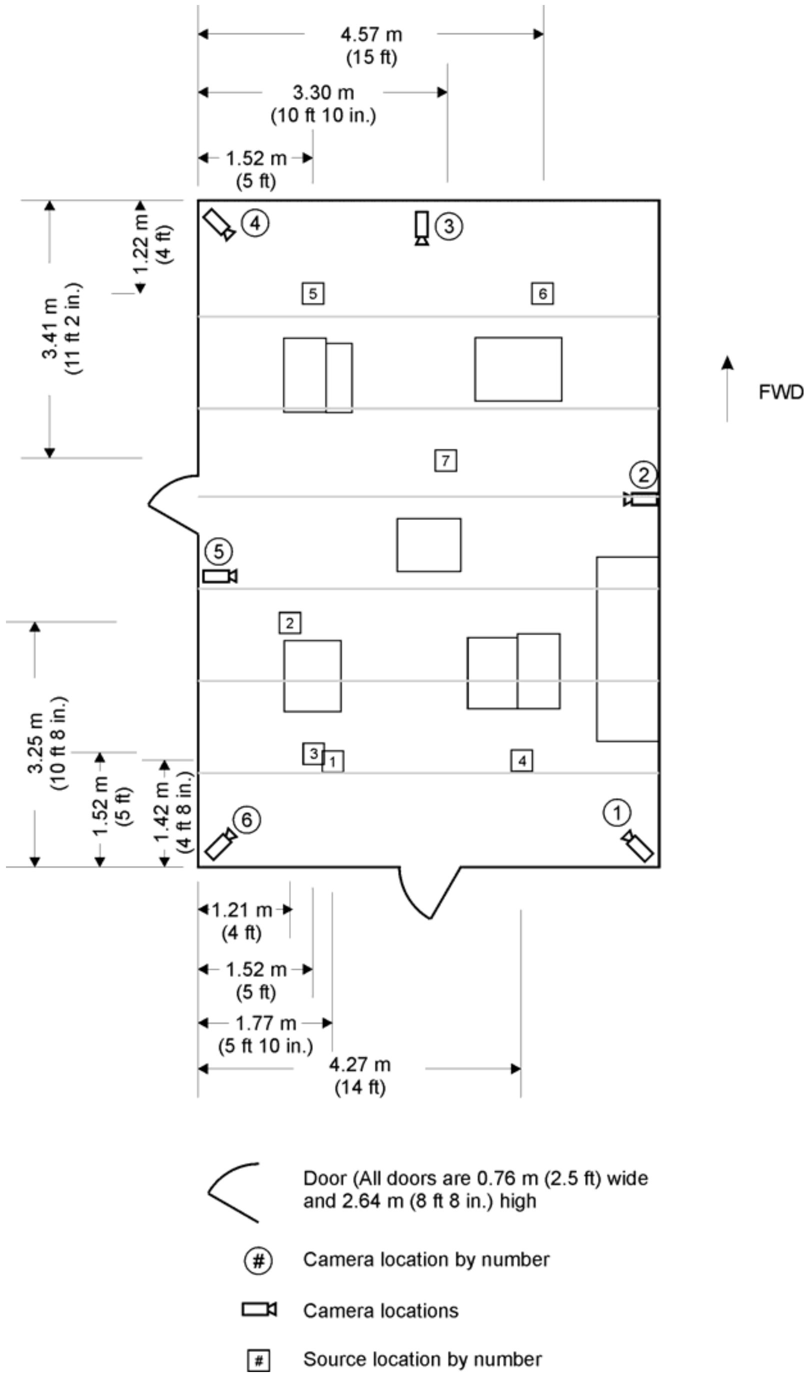

Fig. 17 — Source locations within Compartment 1

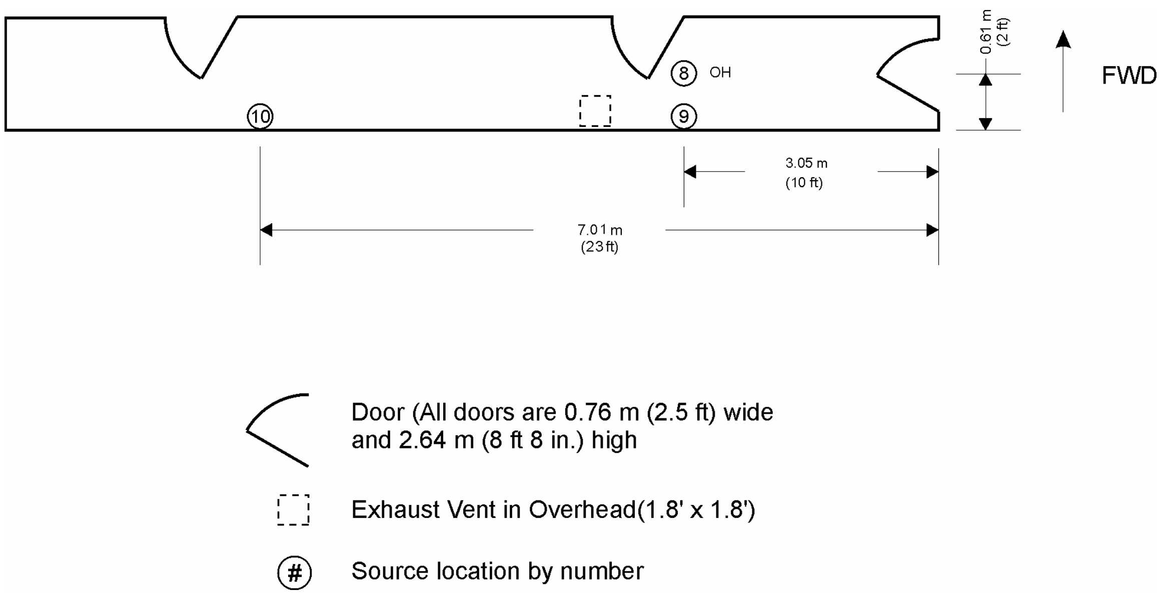

Fig. 18 — Source locations within the passageway

Table 7 — The Location of Fire or Nuisance Sources in Reference to the Aft and Port Bulkheads

Location number	**From Aft (m (ft))**	**From Port (m (ft))**	**Height above deck (m (ft))**
1	1.42 (4.7)	1.78 (5.8)	0.00 (0.0)
2	3.25 (10.7)	1.22 (4.0)	0.00 (0.0)
3	1.52 (5.0)	1.52 (5.0)	0.00 (0.0)
4	1.42 (4.7)	4.24 (13.9)	0.00 (0.0)
4A	1.42 (4.7)	4.24 (13.9)	0.76 (2.5)
5	7.62 (25.0)	1.52 (5.0)	0.00 (0.0)
6	7.62 (25.0)	4.58 (15.0)	0.00 (0.0)
7	5.41 (17.8)	3.30 (10.8)	0.00 (0.0)
Passageway Location	Aft to forward (m (ft))	Port to starboard (m (ft))	Deck to overhead (m (ft))
8	0.61 (2.0)	7.32 (24.0)	2.74 (9.0)
9	0.00 (0.0)	7.32 (24.0)	0.00 (0.0)
10	0.00 (0.0)	2.74 (9.0)	0.00 (0.0)

The selection of sources was based on the previous studies conducted within the program [2, 6]. Additional sources and modifications were made to expand the range of scenarios. Tables 8 and 9 present the fire and nuisance sources, respectively that were used in this test series. Photographs of sources are provided in Appendix B.

Table 8 — List of Fire Sources Used During Testing

No.	Fire Source ID	Description
1	Smoldering Cable Bundle	A bundle of cable consisting of 5 pieces, each 0.3 m (1 ft) in length (Monroe Cable Co., LSTSGU-9, M24643/16-03UN XLPOLYO), surrounding one 500 W cartridge heater (Vulcan, TB507A) was used to create a smoldering source. The heater was energized using a variable transformer set at 96 VAC (80% of 120 V max).
2	Flaming Cardboard Box	A total of four boxes 0.26 x 0.26 x 0.11m (10 x 10 x 4.5 in.) were loosely filled with crumpled brown paper (1.1 m x 0.6 m) and positioned in two rows side by side with a 2.5 cm flue space between the two rows. The boxes were oriented in each row end to end so that the 0.26 x 0.26 m sides faced the opposite row across the flue space. A butane lighter was used to light a bottom corner of a box in the flue space so that flames propagated up the flue space and involved both boxes.
3	Flaming Cardboard Box (plastic)	A total of four boxes 0.26 x 0.26 x 0.11m (10 x 10 x 4.5 in.) were loosely filled with plastic bubble wrap (1.1 m x 0.6 m) and positioned in two rows side by side with a 2.5 cm flue space between the two rows. The boxes were oriented in each row end to end so that the 0.26 x 0.26 m sides faced the opposite row across the flue space. A butane lighter was used to light a bottom corner of a box in the flue space so that flames propagated up the flue space and involved both boxes.
4	Smoldering Bag of Trash	One bag 60 x 57.5 cm, 32.2 L, 15µm (24 x 23 in., 7-10 gal, 0.6 mil) filled with ordinary trash obtained from the office (printer paper, paper towels, plastic, mailing packs, envelopes) was used with one 500 W cartridge heater (Vulcan, TB507A) energized to 120 VAC. The heater was placed on top of a piece of gypsum board beneath the closed bag.
5	Smoldering Trash Can	One 60 x 57.5 cm, 32.2 L, 15µm (24 x 23 in., 7-10 gal, 0.6 mil) bag was filled with ordinary trash obtained from the office (printer paper, paper towels, paper cups) and placed in a metal trash can measuring 30.5 cm deep x 40.6 cm x 22.9 cm (12 in. deep x 16 in. x 9in.). A single piece of 8 ½ x 11 in. paper is crumpled into a ball making a pocket and placed on top of the open bag of trash. A lit cigarette is then placed in the center of the pocket of the crumpled paper ball and left to smolder.

Table 8 — List of Fire Sources Used During Testing
(Continued)

No.	Fire Source ID	Description
6	Smoldering Wire	Two pieces of 1 m long wire was powered in parallel at 6 VAC (with no current limit) for 1 minute. The wire was constructed of 10, 0.1 mm strands, insulated with PVC to a radial thickness of 0.3 mm, with a cross-sectional area of 0.078 mm^2. The test follows British Standard BS6266.
7	Smoldering Printed Circuit Board	The test was designed to replicate electronic fires involving circuit boards. A FR-4 substrate board was energized at 9 V, 8.5 amps to produce smoldering substrate and a traveling arc between two 50 mil wide copper tracks, spaced 50 mil apart.
8	Smoldering Laundry	Three miscellaneous pieces of clothing (cotton) were folded and piled one on top of another. One 500 W cartridge heater (Vulcan, TB507A) powered at 120 VAC was placed in the middle of the pile and set to 96 VAC (80% of 120 V max).
9	Smoldering Mattress and Bedding	One 0.3 x 0.3 m (12 x 12 in.) section of Navy mattress (MIL-M-18351F(SH), 11.4 cm thick Safeguard polychloroprene foam core covered with a fire retardant cotton ticking) was under a loose pile of bedding, including one polyester batting, quilted mattress pad (Volunteer Blind Industries, GS-07F-14865, DDD-P-56E), one sheet (Federal Specification DDD-S-281) and one brown bed spread (Fed Spec DDD-B-151) (each 0.6 x 0.6 m). One 500 W cartridge heater (Vulcan, TB507A) energized at 120 VAC was located between the bedding and the mattress ticking.
10	Smoldering Computer Monitor	A 15-inch standard monitor was exposed to an internal heat source. One 500 W cartridge heater (Vulcan, TB507A) was inserted into a 1.6 cm (0.625 in.) hole at the bottom corner of the monitor (either front or back). The cartridge heater was energized to 80% of the 120 VAC supply.
11	Flaming Trash Can	One 60 x 57.5 cm, 32.2 L, 15μm (24 x 23 in., 7-10 gal, 0.6 mil) bag was filled with ordinary trash obtained from the office (printer paper, paper towels, paper cups) and placed in a metal trash can. The open bag of trash was lit at the top with a butane lighter.
12	Flaming Mattress and Bedding	A butane lighter was used to ignite the top bedding material in the corner of the mattress and bedding setup.

Table 9 — List of Nuisance Sources Used During Testing

No.	Nuisance Source ID	Description
1	Person working in compartment	A person working in view of the cameras. Duration is test dependant.
2	People Working in compartment	Multiple people working in view of the cameras. Duration is test dependant.
3	Waving Materials	Waving a white t-shirt. The material was waved/shaken by a person moving through the space and stopping in front of each camera for a short period of time.
4	Cigarette Smoke	Four smokers in the space, each smoking a single cigarette
5	Spray Aerosol	Five second spray intervals at multiple locations in the test space. Two aerosols were used: 1) Old Spice High Endurance Anti-perspirant and deodorant (pure sport). 2) Lysol disinfectant spray.
6	Toaster: Overdone Toast	A Magic Chef model number N-10 120 V AC 60 Hz 1500W Toaster with 4 slices of white bread toasted at the darkest setting for three cycles.
7	Welding	Welding of two pieces of steel using an arc welder operating at 150 amps using 7018 rods.
8	Grinding Unpainted Steel	Grinding metal with a 3 ½” power hand grinder for approximately 5 minutes.
9	Sunlight	Open outside rollup delivery door to let sunlight shine in through the open test compartment door and observation windows. The window was located on the starboard bulkhead 3.10 m (10 ft 2 in.) from the aft bulkhead. The window measured 1.45 m (4 ft 9 in.) high and 1.19 m (3 ft 11 in.) wide. The window began at deck level and was usually cover by a square piece of drywall when the sunlight tests were not being conducted.
10	Flash Light	Person carrying a flashlight and shining it towards the various sensors
11	Flash Bulb	Person with camera flash in space taking pictures of the various sensors

4.5 Test Procedure

The general test procedure was to synchronize the time of all the instrumentation and then to initiate the following list:

Start acoustic tape recorder
Start acoustic data acquisition
Start DVR recorder Video 3
Start DVR recorder Video 4
Start DVR recorder Video 1
Start DVR recorder Video 2
Start LWVD (1 & 2)
Start NRL SBVS shelf data logger
Start DAQ data logger
Start VCR's
Set baseline for VSD-8
Check that Signifire is running and the logger is cleared
Clear SFA alarm menu
Reset Notifier and EST alarm panels
Confirm that FireWorks (the EST alarm panel interface software) is running
Record time of Notifier and EST panel (HH:MM:SS)
Record video detection and timestamp time (HH:MM:SS)
Initiate source
Record fire ignition (HH:MM:SS) and Notifier trigger

The test was terminated after all alarms had occurred or after conditions were deemed to have reached a maximum or steady-state level, such that no other detection alarms were anticipated. The test space was ventilated until all detection systems returned to normal background level. Each video signal was recorded using either a DVR or VCR. Table 10 details the test video record, specifying the specific camera and DVR/VCR setups for all of the tests.

Table 10 — Test Video Record

Video Recorder	Signal Source	Camera Location During Test Set 1, 2, 3, and 4	Camera Location During Test Set 5 and 6	Camera Location During Test Set 7
DVR 1	Nightvision Camera 8			Passageway facing Starboard (location 2)
DVR 2	Nightvision Camera 7			Passageway facing port (location 1)
DVR 3	DC-393 Camera 6			Passageway facing Starboard (location 2)
DVR 4	DC –393 Camera 5			Location 5
VCR 1	DC-14 Camera 1			Passageway facing port (location 1)

Table 10 — Test Video Record
(Continued)

Video Recorder	Signal Source	Camera Location During Test Set 1, 2, 3, and 4	Camera Location During Test Set 5 and 6	Camera Location During Test Set 7
VCR 2	DC-14 Camera 3	1	3	Passageway facing port (location 1)
VCR 3	DC-14 Camera 2	1	2	Location 2
VCR 4	DC-14 Camera 4	1	4	Passageway facing Starboard (location 2)

5.0 TEST RESULTS AND DISCUSSION

This test series was divided into seven sets of tests as follows:

1. VID system inter-channel reproducibility for multiple, identical video image feeds
2. VID performance for six optimized, collocated cameras
3. Optimized cameras - effect of lighting conditions and varied sources, six cameras collocated
4. Varied camera settings – effect of lighting conditions and varied sources, six cameras collocated
5. Optimized cameras distributed around test compartment with varying fire sources
6. Optimized cameras distributed around test compartment with varying nuisance sources
7. Optimized cameras in passageway

These sets of tests focused on specific objectives and are characterized by various changes in the test setup and procedures. The details of each set of tests are described below. Table 11 to Table 17 present the complete test matrices for all seven sets of tests conducted during Test Series 2. The tables contain all test numbers applicable to each test set. Some tests are contained in multiple sets.

Table 11 — Test Matrix for Volume Sensor 2 Test Set 1, Comparison of Optimized Cameras (1 Camera Image Split to 4 Inputs of a VID System)

Test Number	Date	Source	Location	Camera Setting	Illumination (Fc)
52	8_19_03	Flaming Boxes	1	Optimum	14
54	8_19_03	Flaming Boxes	1	Optimum	14
254	2_17_04	Flaming Boxes	1	Optimum	14
255	2_17_04	Flaming Boxes	1	Optimum	14
53	8_19_03	Flaming Boxes	2	Optimum	14
55	8_19_03	Flaming Boxes	2	Optimum	14
256	2_17_04	Flaming Boxes	2	Optimum	14
257	2_17_04	Flaming Boxes	2	Optimum	14
56	8_19_03	Smoldering Laundry	2	Optimum	14
57	8_19_03	Smoldering Laundry	2	Optimum	14
258	2_17_04	Smoldering Laundry	2	Optimum	14
259	2_17_04	Smoldering Laundry	2	Optimum	14

Table 12 — Test Matrix for Test Series 2 Test Set 2, Response of Multi-Camera VID Systems to Very Similar Images from Six Collocated Cameras at Location 1

Test Number	Date	Source	Location	Camera Setting	Illumination (Fc)
7	7_23_03	Flaming Bedding	1	Optimum	14
14	7_24_03	Flaming Bedding	1	Optimum	14
19	7_29_03	Flaming Boxes	1	Optimum	14
20	7_29_03	Flaming Boxes	1	Optimum	14
21	7_29_03	Flaming Boxes	1	Optimum	14
22	7_29_03	Flaming Boxes	1	Optimum	14
260	2_18_04	Flaming Boxes	1	Optimum	14
276	2_19_04	Flaming Boxes	1	Optimum	14
10	7_23_03	Flaming Boxes	2	Optimum	14
16	7_24_03	Flaming Boxes	2	Optimum	14
23	7_29_03	Flaming Boxes	2	Optimum	14
24	7_29_03	Flaming Boxes	2	Optimum	14
25	7_29_03	Flaming Boxes	2	Optimum	14
26	7_29_03	Flaming Boxes	2	Optimum	14
277	2_19_04	Flaming Boxes	2	Optimum	14
278	2_19_04	Flaming Boxes	2	Optimum	14
27	7_29_03	Smoldering Cable	1	Optimum	14
28	7_29_03	Smoldering Cable	1	Optimum	14
29	7_29_03	Smoldering Cable	1	Optimum	14
8	7_23_03	Smoldering Cable	2	Optimum	14
9	7_23_03	Smoldering Cable	2	Optimum	14
15	7_24_03	Smoldering Cable	2	Optimum	14
6	7_23_03	Smoldering Laundry	1	Optimum	14
11	7_23_03	Smoldering Laundry	1	Optimum	14
12	7_23_03	Smoldering Laundry	1	Optimum	14
13	7_24_03	Smoldering Laundry	1	Optimum	14
279	2_19_04	Smoldering Laundry	2	Optimum	14
280	2_19_04	Smoldering Laundry	2	Optimum	14

Table 13 — Test Matrix for Test Series 2 Test Set 3, Optimized Cameras - Effect of lighting Conditions and Varied Sources, Six Cameras Collocated with the Same Image

Test Number	Date	Source	Location	Camera Setting	Illumination (Fc)
7	7_23_03	Flaming Bedding	1	Optimum	14
14	7_24_03	Flaming Bedding	1	Optimum	14
18	7_24_03	Flaming Bedding	1	Optimum	7
19	7_29_03	Flaming Boxes	1	Optimum	14
20	7_29_03	Flaming Boxes	1	Optimum	14
21	7_29_03	Flaming Boxes	1	Optimum	14
22	7_29_03	Flaming Boxes	1	Optimum	14
85	8_27_03	Flaming Boxes	1	Optimum	Red
86	8_27_03	Flaming Boxes	1	Optimum	Red
10	7_23_03	Flaming Boxes	2	Optimum	14
16	7_24_03	Flaming Boxes	2	Optimum	14
23	7_29_03	Flaming Boxes	2	Optimum	14
24	7_29_03	Flaming Boxes	2	Optimum	14
25	7_29_03	Flaming Boxes	2	Optimum	14
26	7_29_03	Flaming Boxes	2	Optimum	14
87	8_27_03	Flaming Boxes	2	Optimum	Red
88	8_27_03	Flaming Boxes	2	Optimum	Red
27	7_29_03	Smoldering Cable	1	Optimum	14
28	7_29_03	Smoldering Cable	1	Optimum	14
29	7_29_03	Smoldering Cable	1	Optimum	14
8	7_23_03	Smoldering Cable	2	Optimum	14
9	7_23_03	Smoldering Cable	2	Optimum	14
15	7_24_03	Smoldering Cable	2	Optimum	14
6	7_23_03	Smoldering Laundry	1	Optimum	14
11	7_23_03	Smoldering Laundry	1	Optimum	14
12	7_23_03	Smoldering Laundry	1	Optimum	14
13	7_24_03	Smoldering Laundry	1	Optimum	14
17	7_24_03	Smoldering Laundry	1	Optimum	7
89	8_27_03	Smoldering Laundry	2	Optimum	Red
90	8_27_03	Smoldering Laundry	2	Optimum	Red

Table 14 — Test Matrix for Test Series 2 Test Set 4 Varied Camera Settings – Effect of Lighting Conditions and Varied Sources, Six Cameras Collocated*

Test Number	Date	Source	Location	Camera Setting	Illumination (Fc)
50	8_18_03	8 Flaming Boxes	2	Mix	14
31	8_5_03	Flaming Boxes	1	Mix	14
32	8_5_03	Flaming Boxes	1	Mix	14
33	8_5_03	Flaming Boxes	1	Mix	14
34	8_5_03	Flaming Boxes	1	Mix	14
39	8_6_03	Flaming Boxes	1	Mix	14
40	8_6_03	Flaming Boxes	1	Mix	14
58	8_20_03	Flaming Boxes	1	Mix	14
59	8_20_03	Flaming Boxes	1	Mix	14
60	8_20_03	Flaming Boxes	1	Mix	14
78	8_26_03	Flaming Boxes	1	Mix	28
79	8_26_03	Flaming Boxes	1	Mix	28
80	8_26_03	Flaming Boxes	1	Mix	28
66	8_21_03	Flaming Boxes	1	Mix	7
67	8_21_03	Flaming Boxes	1	Mix	7
74	8_25_03	Flaming Boxes	1	Mix	Red
75	8_25_03	Flaming Boxes	1	Mix	Red
272	2_19_04	Flaming Boxes	1	Mix	14
273	2_19_04	Flaming Boxes	1	Mix	14
35	8_5_03	Flaming Boxes	2	Mix	14
36	8_5_03	Flaming Boxes	2	Mix	14
37	8_5_03	Flaming Boxes	2	Mix	14
38	8_5_03	Flaming Boxes	2	Mix	14
45	8_6_03	Flaming Boxes	2	Mix	14
46	8_6_03	Flaming Boxes	2	Mix	14
61	8_20_03	Flaming Boxes	2	Mix	14
62	8_20_03	Flaming Boxes	2	Mix	14
63	8_20_03	Flaming Boxes	2	Mix	14
81	8_26_03	Flaming Boxes	2	Mix	28
82	8_26_03	Flaming Boxes	2	Mix	28
68	8_21_03	Flaming Boxes	2	Mix	7
69	8_21_03	Flaming Boxes	2	Mix	7
72	8_25_03	Flaming Boxes	2	Mix	Red
73	8_25_03	Flaming Boxes	2	Mix	Red
269	2_18_04	Flaming Boxes	2	Mix	14
274	2_19_04	Flaming Boxes	2	Mix	14
44	8_6_03	Flaming Boxes	3	Mix	14
42	8_6_03	Smoldering Laundry	1	Mix	0
30	8_5_03	Smoldering Laundry	1	Mix	14
41	8_6_03	Smoldering Laundry	1	Mix	14
51	8_18_03	Smoldering Laundry	1	Mix	14
43	8_6_03	Smoldering Laundry	2	Mix	14
47	8_6_03	Smoldering Laundry	2	Mix	14
48	8_18_03	Smoldering Laundry	2	Mix	14
49	8_18_03	Smoldering Laundry	2	Mix	14
64	8_20_03	Smoldering Laundry	2	Mix	14
65	8_20_03	Smoldering Laundry	2	Mix	14
83	8_26_03	Smoldering Laundry	2	Mix	28
84	8_26_03	Smoldering Laundry	2	Mix	28
70	8_21_03	Smoldering Laundry	2	Mix	7
71	8_21_03	Smoldering Laundry	2	Mix	7
76	8_25_03	Smoldering Laundry	2	Mix	Red
77	8_25_03	Smoldering Laundry	2	Mix	Red
271	2_19_04	Smoldering Laundry	2	Mix	14
275	2_19_04	Smoldering Laundry	2	Mix	14

* Note: Some tests were conducted in Test Set 4 that were not used in the analysis but are listed in Table 14 for completeness. Test 42 where an illumination level of 0 Fc was tested and Test 50 where 8 boxes were used in the source instead of the normal 4.

Table 15 — Test Matrix for Test Series 2 Test Set 5 Optimized Cameras Distributed Around Test Compartment with Varying Fire Sources

Test Number	Date	Source	Location	Camera Setting	Illumination (Fc)
91	9_4_03	Flaming Boxes	1	Optimum	14
92	9_4_03	Flaming Boxes	1	Optimum	14
97	9_5_03	Flaming Boxes	1	Optimum	14
98	9_5_03	Flaming Boxes	1	Optimum	14
160	10_2_03	Flaming Boxes	1	Optimum	14
93	9_4_03	Flaming Boxes	2	Optimum	14
94	9_4_03	Flaming Boxes	2	Optimum	14
99	9_5_03	Flaming Boxes	4	Optimum	14
100	9_5_03	Flaming Boxes	4	Optimum	14
231	11_18_03	Flaming Boxes	4	Optimum	14
232	11_18_03	Flaming Boxes	4	Optimum	14
238	11_19_03	Flaming Boxes	4	Optimum	14
101	9_5_03	Flaming Boxes	5	Optimum	14
104	9_8_03	Flaming Boxes	5	Optimum	14
229	11_18_03	Flaming Boxes	5	Optimum	14
230	11_18_03	Flaming Boxes	5	Optimum	14
237	11_19_03	Flaming Boxes	5	Optimum	14
105	9_8_03	Flaming Boxes	6	Optimum	14
106	9_8_03	Flaming Boxes	6	Optimum	14
161	10_23_03	Flaming Boxes	6	Optimum	14
162	10_23_03	Flaming Boxes	6	Optimum	14
163	10_23_03	Flaming Boxes	6	Optimum	14
166	10_24_03	Flaming Boxes	6	Optimum	14
234	11_18_03	Flaming Boxes (plastic)	4	Optimum	14
236	11_19_03	Flaming Boxes (plastic)	4	Optimum	14
233	11_18_03	Flaming Boxes (plastic)	5	Optimum	14
235	11_18_03	Flaming Boxes (plastic)	5	Optimum	14
118	9_18_03	Flaming Trash Can	4	Optimum	14
119	9_18_03	Flaming Trash Can	4	Optimum	14
120	9_18_03	Flaming Trash Can	4	Optimum	14
116	9_18_03	Flaming Trash Can	5	Optimum	14
117	9_18_03	Flaming Trash Can	5	Optimum	14
121	9_18_03	Flaming Trash Can	5	Optimum	14
123	9_23_03	Smoldering Cable	1	Optimum	14
124	9_23_03	Smoldering Cable	4	Optimum	14
125	9_23_03	Smoldering Cable	4	Optimum	14
122	9_23_03	Smoldering Cable	5	Optimum	14
126	9_23_03	Smoldering Cable	5	Optimum	14
115	9_18_03	Smoldering Cable	6	Optimum	14
127	9_23_03	Smoldering Cable	6	Optimum	14
164	10_23_03	Smoldering Cable	6	Optimum	14
165	10_23_03	Smoldering Cable	6	Optimum	14
182	10_28_03	Smoldering Circuit Board	6	Optimum	14
183	10_28_03	Smoldering Circuit Board	6	Optimum	14
103	9_5_03	Smoldering Laundry	1	Optimum	14
107	9_8_03	Smoldering Laundry	1	Optimum	14
108	9_8_03	Smoldering Laundry	1	Optimum	14
95	9_4_03	Smoldering Laundry	2	Optimum	14
96	9_4_03	Smoldering Laundry	2	Optimum	14
245	11_19_03	Smoldering Laundry	4	Optimum	14
109	9_8_03	Smoldering Laundry	4	Optimum	14
110	9_8_03	Smoldering Laundry	4	Optimum	14
111	9_8_03	Smoldering Laundry	5	Optimum	14
112	9_8_03	Smoldering Laundry	5	Optimum	14
113	9_8_03	Smoldering Laundry	6	Optimum	14
114	9_8_03	Smoldering Laundry	6	Optimum	14
175	10_27_03	Smoldering Laundry	6	Optimum	14
176	10_27_03	Smoldering Laundry	6	Optimum	14
177	10_27_03	Smoldering Laundry	6	Optimum	14
168	10_24_03	Smoldering Mattress	6	Optimum	14
169	10_24_03	Smoldering Mattress	6	Optimum	14
170	10_24_03	Smoldering Monitor	6	Optimum	14
171	10_24_03	Smoldering Monitor	6	Optimum	14
149	9_30_03	Smoldering Monitor	4A	Optimum	14
158	9_30_03	Smoldering Monitor	4A	Optimum	14
159	9_30_03	Smoldering Monitor	4A	Optimum	14
167	10_24_03	Smoldering Trash	6	Optimum	14
172	10_24_03	Smoldering Trash	6	Optimum	14
173	10_27_03	Smoldering Trash	6	Optimum	14
174	10_27_03	Smoldering Trash	6	Optimum	14
178	10_27_03	Smoldering Trash	6	Optimum	14
179	10_28_03	Smoldering Wire	6	Optimum	14
180	10_28_03	Smoldering Wire	6	Optimum	14
184	10_28_03	Smoldering Wire	6	Optimum	14

Table 16 — Test Matrix for Test Series 2 Test Set 6 Optimized Cameras Distributed Around Test Compartment with Varying Nuisance Sources

Test Number	Date	Source	Location	Camera Setting	Illumination (Fc)
135	9_24_03	Burnt Toast	4A	Optimum	14
136	9_24_03	Burnt Toast	4A	Optimum	14
139	9_24_03	Burnt Toast	4A	Optimum	14
140	9_24_03	Burnt Toast	4A	Optimum	14
137	9_24_03	Burnt Toast	4A	Optimum	14
138	9_24_03	Burnt Toast	4A	Optimum	14
152	9_30_03	Burnt Toast	4A	Optimum	14
153	9_30_03	Burnt Toast	4A	Optimum	14
185	10_28_03	Cigarette Smoke	Roaming	Optimum	14
155	9_30_03	Cutting Steel	4	Optimum	14
156	9_30_03	Cutting Steel	4	Optimum	14
239	11_19_03	Flash Bulbs	Roaming	Optimum	14
240	11_19_03	Flash Bulbs	Roaming	Optimum	14
226	11_17_03	Flash Bulbs	Roaming	Optimum	14
241	11_19_03	Flash Light	Roaming	Optimum	14
242	11_19_03	Flash Light	Roaming	Optimum	14
244	11_19_03	Flash Light	Roaming	Optimum	14
243	11_19_03	Flash Light	Roaming	Optimum	14
186	10_28_03	Grinding Steel	2	Optimum	14
187	10_28_03	Grinding Steel	2	Optimum	14
128	9_23_03	Man in Compartment	Roaming	Optimum	14
129	9_24_03	Man in Compartment	Roaming	Optimum	14
131	9_24_03	Man in Compartment	Roaming	Optimum	14
143	9_30_03	Man in Compartment	Roaming	Optimum	14
144	9_30_03	Man in Compartment	Roaming	Optimum	14
147	9_30_03	Multiple people working	Roaming	Optimum	14
148	9_30_03	Multiple people working	Roaming	Optimum	14
133	9_24_03	Spray Aerosol (lysol)	Roaming	Optimum	14
134	9_24_03	Spray Aerosol (lysol)	Roaming	Optimum	14
225	11_17_03	Spray Aerosol (lysol)	Roaming	Optimum	14
228	11_17_03	Spray Aerosol (lysol)	Roaming	Optimum	14
150	9_30_03	Spray Aerosol (old spice)	Roaming	Optimum	14
151	9_30_03	Spray Aerosol (old spice)	Roaming	Optimum	14
141	9_25_03	Sunlight	Roaming	Optimum	14
142	9_25_03	Sunlight	Roaming	Optimum	14
154	9_30_03	Welding (Stick)	1	Optimum	14
157	9_30_03	Welding (Stick)	1	Optimum	14
227	11_17_03	White t-shirt	Roaming	Optimum	14
130	9_24_03	White t-shirt	Roaming	Optimum	14
132	9_24_03	White t-shirt	Roaming	Optimum	14
145	9_30_03	White t-shirt	Roaming	Optimum	14
146	9_30_03	White t-shirt	Roaming	Optimum	14

Table 17 — Test Matrix for Test Series 2 Test Set 7, Optimized Cameras in Passageway

Test Number	Date	Source	Location	Camera Setting	Illumination (Fc)
195	11_10_03	Flaming Boxes	9	Optimum	7
196	11_10_03	Flaming Boxes	9	Optimum	7
197	11_10_03	Flaming Boxes	9	Optimum	7
191	11_7_03	Flaming Boxes	9	Optimum	7
192	11_7_03	Flaming Boxes	9	Optimum	7
201	11_10_03	Flaming Boxes	10	Optimum	7
202	11_10_03	Flaming Boxes	10	Optimum	7
190	11_7_03	Flaming Boxes (plasic)	9	Optimum	7
198	11_10_03	Flaming Boxes (plastic)	9	Optimum	7
199	11_10_03	Flaming Boxes (plastic)	9	Optimum	7
200	11_10_03	Flaming Boxes (plastic)	9	Optimum	7
194	11_10_03	Flaming Cable	8	Optimum	7
215	11_13_03	Flaming Cable	8	Optimum	7
216	11_13_03	Flaming Cable	8	Optimum	7
218	11_14_03	Flaming Cable	8	Optimum	7
219	11_14_03	Flaming Cable	8	Optimum	7
220	11_14_03	Flaming Cable	8	Optimum	7
217	11_14_03	Flaming Cable	8	Optimum	7
209	11_12_03	Flash Bulbs	Roaming	Optimum	7
207	11_12_03	Flash Light	Roaming	Optimum	7
208	11_12_03	Flash Light	Roaming	Optimum	7
205	11_12_03	Man in Compartment	Roaming	Optimum	7
206	11_12_03	Man in Compartment	Roaming	Optimum	7
210	11_12_03	Multiple people working and flash bulb	Roaming	Optimum	7
211	11_12_03	Multiple people working and flash bulb	Roaming	Optimum	7
188	11_7_03	Smoldering Cable	8	Optimum	7
189	11_7_03	Smoldering Cable	8	Optimum	7
193	11_7_03	Smoldering Cable	8	Optimum	7
203	11_12_03	Smoldering Cable	9	Optimum	7
204	11_12_03	Smoldering Cable	9	Optimum	7
221	11_14_03	Smoldering Cable	10	Optimum	7
223	11_14_03	Smoldering Cable	10	Optimum	7
224	11_14_03	Smoldering Cable	10	Optimum	7
213	11_13_03	Sunlight	Roaming	Optimum	7
214	11_13_03	Sunlight	Roaming	Optimum	7
212	11_13_03	Sunlight	Roaming	Optimum	7
222	11_14_03	White t-shirt	Roaming	Optimum	7

1. VID system inter-channel reproducibility for multiple, identical video image feeds

The first set of tests examined each VID system response to identical, optimized camera images. An optimized image from each of two collocated Sony SSC-DC14 cameras was split into four signals. The four identical images from one camera were fed into the SFA system. The other four identical images from the second camera were fed into the SigniFire system. Smoldering laundry in Location 2 and flaming boxes in Location 1 and Location 2 were used as sources (see Figure 17 for source locations). The objective was to examine the VID systems for performance reproducibility, determining if any variations in detection times occur between camera inputs. In addition, if differences in the detection times did occur, it was the aim to determine possible causes and if the deviations in alarm times would be large enough to skew the results in the following test sets.

2. VID performance for six optimized, collocated cameras

   The second set of tests examined each VID system response to a cluster of cameras looking at essentially the same image. A cluster of six cameras, two SSC-DC393 and four SSC-DC14, were positioned at Location 1. Figure 19 shows a photograph of the six camera setup along with the nightvision cameras. All six standard cameras were optimally set to yield images that were as identical as possible. The six camera images were fed into the SFA and SigniFire systems. Sources included, flaming boxes, smoldering cable and smoldering laundry in Location 1 and Location 2. The objective of this test set was to determine the variations in VID performance for the similar video images from the collocated camera setup. Ideally, the performance would be exactly the same, thus removing any camera dependency in Test Sets 3 and 4, in which other test variables were systematically changed.

3. Optimized cameras - effect of lighting conditions and varied sources on six cameras collocated

   The third set of tests consisted of changing the lighting conditions, sources and source locations while using the six collocated cameras at Location 1, with the camera settings optimized. Sources included flaming boxes and smoldering laundry in Location 1 and Location 2. The illumination levels within the compartment were varied and included 14Fc, 7Fc, and red illumination using a 14 Fc basis. The objective was to examine the effect of varying light levels on VID system operation. A small number of tests were conducted in this test set before it was determined that more information would be obtained, by varying the camera settings (while keeping two at optimal) and illumination levels together, as was then done in Test Set 4.

4. Varied camera settings – effect of lighting conditions and varied sources on six cameras collocated

   The fourth set of tests expanded on the objectives of Test Set 3 by also examining the effect of variations in camera settings on the performance of the VID systems. The focus and iris settings of the cameras were systematically varied for individual cameras to yield optimally set images, dark and light images, and out of focus images. The test conditions evaluated in Set 3 were repeated and expanded to include additional light levels in the space. The cameras remained collocated at Location 1, and sources included the flaming boxes and smoldering laundry positioned at both Location 1 and Location 2.

5. Optimized cameras distributed around test compartment with varying fire sources.

   In Test Set 5, the six cameras were distributed around the compartment and they were set for optimal images. Cameras were placed at all six locations, within Compartment 1, as shown in Figure 17. Model SSC-DC14 cameras were located at Location 1 through 4 while model SSC-DC393 cameras were located at Locations 5 and 6. The objective was to identify the effect of source type, source location, compartment color, and camera location on VID system performance. Source locations consisted of 1, 2, 4, 5, and 6 and the majority of fire sources listed in Table 8 were used in this test set.

6. Optimized cameras distributed around test compartment with varying nuisance sources

The sixth test set was run in parallel with Test Set 5. In addition to the variations in source type and source locations tested in Set 5, various nuisance sources were employed to determine the vulnerability of the VID systems to nuisance source activation. The various nuisance sources are listed in Table 9.

7. Optimized cameras in passageway

The seventh set of tests consisted of moving four cameras, two SSC-DC14 and two SSC-DC393 into the passageway. One of each camera model was located near the overhead at each end of the passageway. Sources included flaming boxes and smoldering cable located on the deck and in the overhead of the passageway. The objective was to examine the effect of compartment geometry and camera type on the commercial VID system performance and the nightvision cameras/LWVD system.

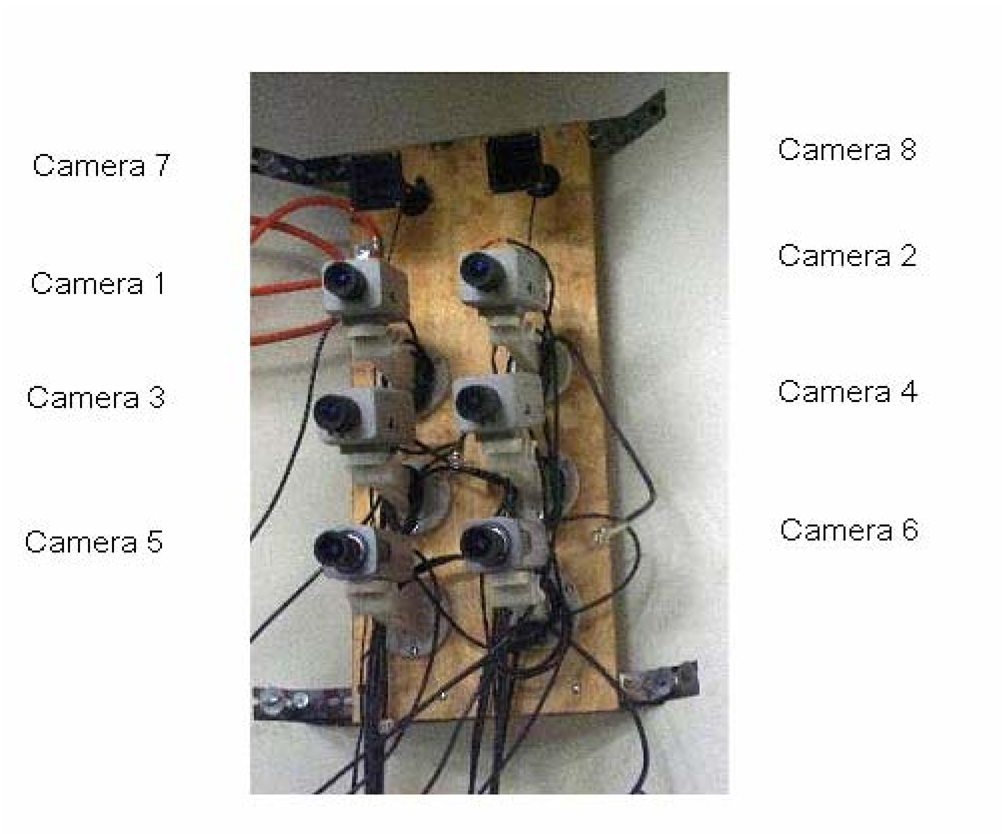

Fig. 19 — Image of camera cluster, Cameras 1 through 8, at Location 1

The primary performance metric measured was the alarm response time for the various detection systems; including the VID systems and the COTS spot-type smoke detection systems. Times to alarm were determined from the digital record of each system and are relative to the time of source initiation. If a detector did not alarm in a test, it was listed as DNA (Did Not Alarm). Source initiation times for each test are provided in the Master Table on the attached CD. The results and discussion section is subdivided by Test Set. Table 18 presents an organizational overview of the results and where they appear in the discussion. The table includes figure IDs with their respective Test Set, VID system, source, source location, and alarm type. The data and number of tables are limited within each Test Set to those that produce useful comparisons. This was done to limit the document size, reduce confusion, and expedite the analysis. The data in its entirety can be seen in the Master Table on the attached CD.

Table 18 — Figures with Their Respective Test Set, VID System, Source, Source Location, and Alarm Type

Test Set	**VID Systems**	**Source**	**Source Location**	**Alarms**	**Figure Number**
1	SFA SigniFire VSD-8	Flaming Boxes Smoldering Laundry	1 and 2	Offsite Fire Smoke	19
2	SFA SigniFire	Flaming Boxes	1 and 2	Offsite Fire Smoke	21 and 22
Source Repeatability	Notifier/EST Ion and Photo	Flaming Boxes Smoldering Laundry	1 and 2	Ion Photo	24, 25, 26, and 27
Source Repeatability	SFA SigniFire	Flaming Boxes Smoldering Laundry	1 and 2	Smoke Fire Offsite	28 and 29
3	SigniFire SFA	Flaming Boxes	1 and 2	Offsite Fire Smoke	31, 32, 33, 34, and 35
4	SFA SigniFire	Flaming Boxes Smoldering Laundry	1 and 2	Smoke Fire Offsite	37, 38, 39, 40, 42, 43, and 44
5	SigniFire SFA VSD-8	Flaming Boxes Smoldering Laundry Flaming Trash Can Smoldering Cable Flaming Boxes (plastic) Trash Fire (smoldering)	4 and 5	Smoke Fire Offsite	46, 47, 48, 49, 50, 51, 52, 53, 54, 55, and 56
7	SFA SigniFire VSD-8	Flaming Boxes Flaming Boxes (plastic) Smoldering Cable Flaming Cable Nuisance Sources	8, 9 and 10	Smoke Fire Offsite	69, 70, 71, 73, 74, 75, 77, 78, 79, 81, 82, 83
7	Notifier EST	Flaming Boxes Flaming Boxes (plastic) Smoldering Cable Flaming Cable Nuisance Sources	8, 9, 10	Ion Photo	72, 76, 80, and 84

5.1 Test Set 1 Results

Test Set 1 was conducted to assess how reproducible the VID system alarm algorithms were to identifying smoke and flame events. To achieve this goal, each video detection system (SFA and SigniFire only) was supplied with four identical video images produced from one of two collocated Sony SSC-DC14 cameras. Each camera signal was split into four identical video signals, using an amplified video splitter. Four identical signals from one camera were fed into the SFA system. The four identical signals from the second camera were fed into the SigniFire system. Unfortunately the VSD-8 system could not be included in this test set due to the fact that there was no label in the history image file to identify which camera was in alarm. Additionally, the VSD outputs were not functioning properly at the time.

The results, presented in Table 19, show that both the SFA and SigniFire system produced alarm times for all four video images with standard deviations of five seconds or less in most cases. In general the flaming algorithms alarmed to the flaming fires when the source was in the line of sight (i.e., Source Location 1), but did not alarm when the fire was behind an obstruction as with Source Location 2. The smoke algorithms alarmed to all the smoldering laundry and to most of the flaming box fires. Test 55 proved to be the most challenging fire to detect for both VID systems. A review of the video for this fire showed that the test did not differ significantly from Test 53, a test with a similar fire source and location. In general, the VID system alarms were quite reproducible across the different video inputs. It can be seen that the standard deviation between alarms for the different camera inputs was below 11 seconds for flaming boxes in Location 1 with average alarm times ranging from about 0.5 to 3.5 minutes. A larger alarm time standard deviation (up to 42 seconds) was observed for the flaming boxes in Location 2. Location 2 was behind an obstruction and for the most part out of the line of sight of the camera. The fire could grow large enough to produce flame heights over the cabinet or visible to the side of the obstruction. This location was, however, more difficult to detect by both flame and smoke algorithms, as the flaming box fires did not produce a large amount of visible smoke nor was the flame, generally, visible to the cameras (see Figure 20). The obscured fire created the largest standard deviations with some cameras not producing an alarm at all. This could be due to the order in which the VID system grabs the image frames as it cycles from one input stream to the next, also known as sequencing. The slower more stable smoldering smoke, which would appear to be the same in each sequenced image, causes a small deviation in alarm times when compared to the flicker of a obscured flame that may or may not appear in sequenced camera images. The SigniFire offsite algorithm produced alarms for all flaming fire regardless of location. The smoldering laundry fires in Location 2 were detected in about 5 to 6 minutes with standard deviations of less than 5 seconds by the smoke alarm algorithms between video inputs. Typically, the offsite and fire algorithms would only alarm to flaming fires as designed. The smoke algorithms typically alarmed whenever visible smoke was present, regardless of the mode of burning. Overall the VID systems using multiple, identical camera images produced consistent activation times. However for the obstructed flaming fires there were a number of cases where the systems had some cameras alarm while others did not.

Table 19 — Alarm Times (Min:Sec) of the SFA and Signifire Video Image Detection Systems to Flaming Boxes and Smoldering Laundry Fires in Source Locations 1 and 2 for a Single Camera Signal Split to Four Inputs of a VID System

SFA Smoke Algorithm								
Test	Source	Location	Input 1	Input 2	Input 3	Input 4	Average	STDEV
52	Flaming Boxes	1	02:26	02:30	02:29	02:27	02:28	00:02
54	Flaming Boxes	1	02:00	01:59	01:57	01:58	01:58	00:01
53	Flaming Boxes	2	02:29	02:34	02:36	02:41	02:35	00:05
55	Flaming Boxes	2	DNA	DNA	DNA	06:02	06:02	
56	Smoldering Laundry	2	05:47	05:46	05:48	05:46	05:47	00:01
57	Smoldering Laundry	2	04:52	04:52	04:48	04:50	04:50	00:02
SFA Fire Algorithm								
52	Flaming Boxes	1	03:41	03:40	03:37	03:43	03:40	00:02
54	Flaming Boxes	1	02:37	02:42	02:33	02:31	02:36	00:05
53	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	
55	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	
56	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
57	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
SigniFire Smoke Algorithm								
52	Flaming Boxes	1	03:35	03:35	03:34	03:31	03:34	00:02
54	Flaming Boxes	1	03:30	03:41	03:30	03:27	03:32	00:06
53	Flaming Boxes	2	06:58	06:58	DNA	07:00	06:59	00:01
55	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	
56	Smoldering Laundry	2	05:19	05:29	05:29	05:21	05:24	00:05
57	Smoldering Laundry	2	05:04	05:03	05:03	04:59	05:50	00:02
SigniFire Fire Algorithm								
52	Flaming Boxes	1	01:19	01:17	01:31	01:08	01:19	00:09
54	Flaming Boxes	1	00:31	00:34	00:52	00:29	00:36	00:11
53	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	
55	Flaming Boxes	2	DNA	DNA	DNA	06:38	06:38	
56	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
57	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
SigniFire Offsite Algorithm								
52	Flaming Boxes	1	03:37	03:42	03:33	03:34	03:37	00:04
54	Flaming Boxes	1	00:45	00:53	00:45	00:45	00:47	00:04
53	Flaming Boxes	2	03:14	04:31	03:14	04:21	03:50	00:42
55	Flaming Boxes	2	03:04	03:10	03:05	03:37	03:14	00:16
56	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
57	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	

DNA = Did Not Alarm

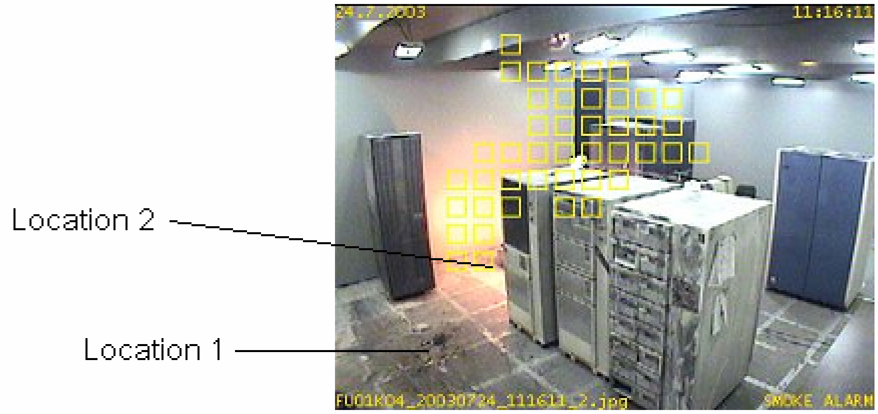

Fig. 20 — Image of flaming box fire obscured by cabinets

Test Set 1 was repeated at the end of testing to include the VSD-8 system after a replacement system had been acquired. This additional testing is referred to as Test Set 1b. All six Sony Cameras were sent out for refurbishing after Test 253. The excessive exposure to smoke had started to degrade the images on some of the cameras. Once the cameras returned from the manufacturer, the compartment was re-configured to repeat Test Set 1. The replacement VSD-8 system was attached to the data acquisition (DAQ) system and output signals were produced and recorded from each camera. The data in Table 20 are the algorithm results for the SFA, SigniFire, and VSD-8 systems for Test Set 1b.

The results for the SFA and SigniFire systems were generally similar to Test Set 1 in that both systems demonstrated the ability to produce repeatable and consistent results. The SigniFire smoke and SFA smoke algorithms performed very well (standard deviations <5 sec.) with the flaming boxes in Location 1. The Signifire smoke algorithm also responded well to the smoldering laundry (standard deviations <5 sec.). The SigniFire offsite algorithm consistently alarmed to the flaming boxes at Location 1 and Location 2. The SigniFire smoke algorithm and the SFA smoke algorithm produced inconsistent results for the flaming boxes at Location 2. The SFA fire algorithm during Test 255 produced inconsistent results by not alarming to the flaming boxes in Location 1. The remaining alarms for the SFA and SigniFire system either were not expected to alarm (i.e., smoldering source with a flame algorithm) or produced alarms with a slightly higher standard deviation (most ≤8 s, maximum <30 sec.).

The VSD-8 system performed poorly in Test Set 1b with inconsistent results for four out of six tests. The only tests resulting in uniform responses for all four video inputs were Test 254, which all alarmed within a standard deviation of 28 seconds, and Test 257, which produced no alarms. The inconsistent alarm times are potentially attributed to slight variations in the setup of the VSD-8 system for each video input. The VSD-8 system requires zones (i.e., boxes) to be manually sized and set in the image for each video input line. Though these zones were set to be as close as possible to the same size on each video input, it is uncertain whether slight differences in size from zone to zone on the different video lines may have an impact.

Table 20 — Test Set 1b Results: Test Set 1 Reproduced to Include the VSD-8 System

SFA Smoke Algorithm								
Test	Source	Location	Input 1	Input 2	Input 3	Input 4	Average	STDEV
254	Flaming Boxes	1	04:46	04:50	04:45	04:48	04:47	00:02
255	Flaming Boxes	1	02:51	02:45	02:49	02:45	02:47	00:03
256	Flaming Boxes	2	DNA	07:15	07:38	07:14	07:22	00:14
257	Flaming Boxes	2	02:23	DNA	02:21	02:24	02:23	00:02
258	Smoldering Laundry	2	05:27	04:47	04:48	04:40	04:55	00:21
259	Smoldering Laundry	2	06:03	05:48	05:46	05:50	05:52	00:08
SFA Fire Algorithm								
254	Flaming Boxes	1	01:03	01:11	00:59	01:16	01:07	00:08
255	Flaming Boxes	1	05:18	DNA	DNA	DNA	05:18	
256	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	
257	Flaming Boxes	2	04:52	DNA	DNA	DNA	04:52	
258	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
259	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
SigniFire Smoke Algorithm								
254	Flaming Boxes	1	02:22	02:22	02:23	02:16	02:21	00:03
255	Flaming Boxes	1	02:01	01:58	02:00	01:58	01:59	00:02
256	Flaming Boxes	2	03:27	02:41	03:20	02:25	02:58	00:30
257	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	
258	Smoldering Laundry	2	04:38	04:39	04:42	04:35	04:38	00:03
259	Smoldering Laundry	2	05:29	05:30	05:28	05:32	05:30	00:02
SigniFire Fire Algorithm								
254	Flaming Boxes	1	00:25	00:22	00:46	00:24	00:29	00:11
255	Flaming Boxes	1	01:04	01:03	01:13	01:01	01:05	00:05
256	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	
257	Flaming Boxes	2	DNA	DNA	DNA	04:11	04:11	
258	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
259	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
SigniFire Offsite Algorithm								
254	Flaming Boxes	1	00:59	01:05	00:58	00:59	01:00	00:03
255	Flaming Boxes	1	01:46	01:45	01:39	01:46	01:44	00:03
256	Flaming Boxes	2	02:21	02:25	02:24	02:12	02:20	00:06
257	Flaming Boxes	2	01:39	01:46	02:19	01:45	01:52	00:18
258	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
259	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	
VSD-8 Smoke Algorithm								
254	Flaming Boxes	1	02:13	03:17	02:59	02:36	02:46	00:28
255	Flaming Boxes	1	DNA	06:08	DNA	01:43	03:55	03:07
256	Flaming Boxes	2	02:43	DNA	DNA	DNA	02:43	
257	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	
258	Smoldering Laundry	2	DNA	DNA	DNA	04:53	04:53	
259	Smoldering Laundry	2	DNA	06:02	05:43	DNA	05:52	00:13

5.2 Test Set 2 Results

Test Set 2 evaluated the consistency of detector performance for the SFA and SigniFire video image detection systems when receiving essentially the same image from six collocated cameras. Again the VSD-8 system was not evaluated in this Test Set because of a system hardware problem resulting in the inability to identify which camera went into alarm. The six cameras

were placed in a cluster at camera Location 1 in the large compartment (see Figure 19) and were configured to optimal image settings as described in Section 4.3.3, Video. The cameras were positioned so that they all had essentially the same image (see Figure 14). Two fire sources, one smoldering and one flaming, were used to evaluate the systems under a constant illumination level of 14 Fc. Table 21 and Table 22 show the results from the flaming box fires at Location 1 and Location 2, respectively. As shown in Figure 20, Source Location 2 is obscured by electrical cabinets from the direct line of sight of the cameras at Camera Location 1. Figure 21 is a bar graph of the results displayed in Table 21.

Table 21 — Time to Alarm (min:sec) for Each VID System[1] with Six Cameras Collocated with Relatively the Same Field of View and Set for Optimal Image Settings Under 14 Fc. Flaming Box Fires in the Direct Line of Sight of the Cameras at Source Location 1.

SFA Smoke Algorithm										
Test	Source	Location	Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6	Average	STDEV
19	Flaming Boxes	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
20	Flaming Boxes	1	03:37	03:36	03:18	03:39	03:33	03:34	03:33	00:08
21	Flaming Boxes	1	DNA	DNA	04:22	DNA	DNA	DNA	04:22	
22	Flaming Boxes	1	DNA	DNA	02:55	04:33	04:23	03:08	03:45	00:50
27	Smoldering Cable	1	DNA	16:49	11:59	11:39	07:57	07:42	11:13	03:43
28	Smoldering Cable	1	DNA	07:18	07:09	06:38	05:47	05:46	06:32	00:44
29	Smoldering Cable	1	DNA	07:42	07:48	07:14	07:05	06:52	07:20	00:24
SFA Fire Algorithm										
19	Flaming Boxes	1	02:39	02:28	02:31	02:36	02:28	02:31	02:32	00:04
20	Flaming Boxes	1	03:01	02:38	02:42	02:24	02:36	02:16	02:36	00:16
21	Flaming Boxes	1	03:27	03:29	03:25	03:17	03:02	03:06	03:18	00:11
22	Flaming Boxes	1	02:35	02:29	02:14	02:11	02:16	02:02	02:18	00:12
27	Smoldering Cable	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
28	Smoldering Cable	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
29	Smoldering Cable	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
SigniFire Fire Algorithm										
19	Flaming Boxes	1	01:56	01:50	01:50	01:59	01:40	01:42	01:49	00:07
20	Flaming Boxes	1	02:04	01:57	01:45	01:41	01:46	01:53	01:51	00:09
21	Flaming Boxes	1	01:47	01:43	01:38	01:40	01:30	01:45	01:40	00:06
22	Flaming Boxes	1	01:38	01:28	01:21	01:22	01:23	01:25	01:26	00:06
27	Smoldering Cable	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
28	Smoldering Cable	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
29	Smoldering Cable	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
SigniFire Offsite Algorithm										
19	Flaming Boxes	1	02:23	02:14	02:13	02:10	02:10	02:07	02:13	00:06
20	Flaming Boxes	1	02:12	02:10	01:55	02:09	02:13	01:58	02:06	00:08
21	Flaming Boxes	1	01:49	01:48	01:46	02:02	01:47	01:45	01:49	00:06
22	Flaming Boxes	1	01:53	01:51	01:31	01:50	01:53	01:47	01:48	00:08
27	Smoldering Cable	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
28	Smoldering Cable	1	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
29	Smoldering Cable	1	DNA	DNA	DNA	27:36	DNA	DNA	27:36	

[1]SigniFire smoke algorithm results not presented due to the unavailability of the algorithm during these early tests.

Table 22 — Time to Alarm (min:sec) for Each VID System[1] with Six Cameras Collocated with Relatively the Same Field of View and Set for the Optimal Settings Under 14 Fc. Flaming Box Fires Outside the Field of View of the Cameras in Source Location 2.

Test	Source	Location	Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6	Average	STDEV
SFA Smoke Algorithm										
10	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
16	Flaming Boxes	2	DNA	07:08	DNA	DNA	04:21	05:44	05:44	01:24
23	Flaming Boxes	2	05:49	06:15	03:40	05:36	05:16	05:15	05:18	00:53
24	Flaming Boxes	2	02:24	DNA	DNA	DNA	08:39	DNA	05:32	04:25
25	Flaming Boxes	2	DNA	DNA	DNA	03:11	02:56	03:01	03:03	00:08
26	Flaming Boxes	2	DNA	03:55	03:51	04:01	03:51	03:52	03:54	00:04
9	Smoldering Cable	2	DNA	DNA	DNA	DNA	09:55	09:59	09:57	00:03
15	Smoldering Cable	2	10:08	08:52	08:48	08:44	08:29	08:29	08:55	00:37
SFA Fire Algorithm										
10	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
16	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
23	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
24	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
25	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
26	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
9	Smoldering Cable	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
15	Smoldering Cable	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
SigniFire Fire Algorithm										
10	Flaming Boxes	2	DNA	DNA	DNA	DNA	07:19	DNA	07:19	
16	Flaming Boxes	2	DNA	DNA	DNA	DNA	04:23	06:43	05:33	01:39
23	Flaming Boxes	2	DNA	DNA	DNA	DNA	06:45	DNA	06:45	
24	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
25	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
26	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
9	Smoldering Cable	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
15	Smoldering Cable	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
SigniFire Offsite Algorithm										
10	Flaming Boxes	2	03:51	04:03	03:50	04:01	03:47	03:46	03:53	00:07
16	Flaming Boxes	2	03:27	03:27	03:28	03:27	03:28	03:28	03:27	00:01
23	Flaming Boxes	2	05:15	06:56	05:26	06:26	04:20	06:04	05:44	00:56
24	Flaming Boxes	2	04:46	05:02	04:50	04:43	04:42	04:38	04:47	00:08
25	Flaming Boxes	2	03:34	03:54	03:38	03:34	03:32	03:38	03:38	00:08
26	Flaming Boxes	2	04:43	05:07	05:14	05:06	04:48	04:48	04:58	00:13
9	Smoldering Cable	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
15	Smoldering Cable	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	

[1].SigniFire smoke algorithm results not presented due to the unavailability of the algorithm during these early tests.

As shown in Table 21 the offsite threshold and fire algorithms for the SigniFire system alarmed consistently for each test in approximately two minutes with standard deviations, calculated across the six cameras, of less than 10 seconds. The SigniFire smoke alarm was not available in the early stages of testing so no results are listed in Table 21 for this algorithm. The SFA system had similar flame algorithm results compared to the SigniFire system with slightly longer alarm times and standard deviations of 4 to 16 seconds. The largest deviation in response time was observed with the SFA smoke algorithm during the flaming box fires at Location 1. As can be seen in the first four rows of Table 21, the results were not repeatable from test to test for the flaming boxes. The results are inconsistent for the six cameras during the tests. For example, during Tests 21 and 22, the SFA smoke algorithm alarmed for some camera images and not for others. This trend of inconsistent smoke alarm activation times for the flaming boxes was observed throughout the entire test program for all the VID systems. The flaming cellulosic

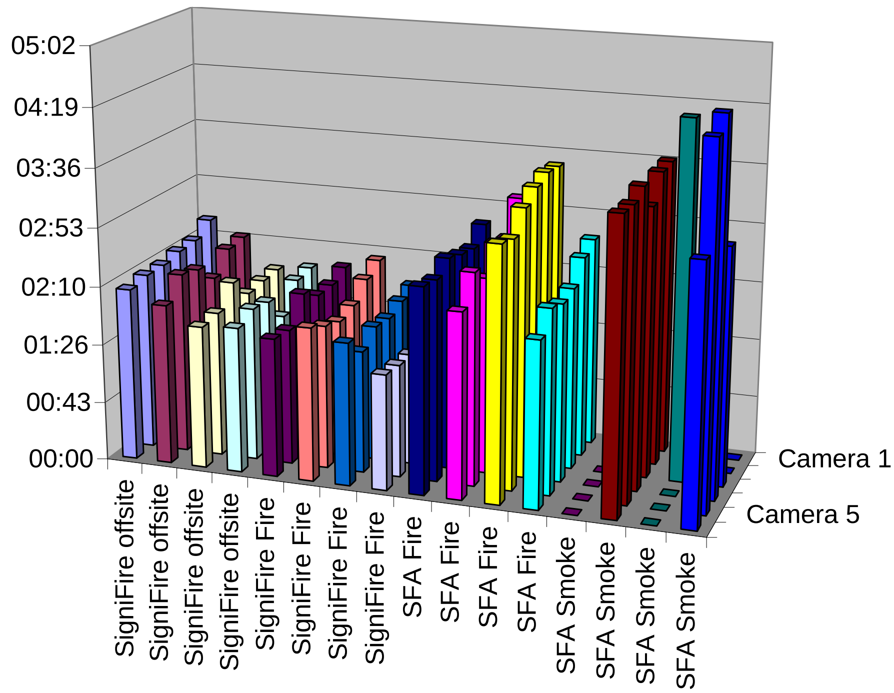

Fig. 21 — Bar graph of results for the optimized cameras clustered in location 1

material of the boxes produced very little visible smoke when burning fairly efficiently. The smoke algorithms of all the VID systems had significant trouble reliably activating to this kind of burning material. When the VID systems did activate a smoke alarm, it was usually late in the burning processes when incomplete combustion was occurring and more visible smoke was produced (e.g., when the interior of the box with paper would smolder). As previously mentioned the SigniFire smoke algorithm was not functioning during this test set, but in later test sets, it generally demonstrated similar smoke alarm trends to the box fires. All the cameras, but camera 1, alarmed to the smoldering cable fires with the SFA smoke algorithm. The standard deviations were significantly higher for the smoldering cable fires due to the difference in detection capabilities between the new and old model cameras. The new model cameras outperformed the older model cameras with quicker detection times. The newer model cameras also slightly outperformed the old model cameras during the flaming tests with the quickest alarm activation in 7 out of 12 tests.

For the most part, the systems showed relatively small deviation in alarm times from camera to camera. The deviations are slightly larger than the standard deviations seen in Test Set 1. The difference between test sets is believed to be due to small variations in camera settings, fields of view, and camera model type for Test Set 2 compared to Test Set 1 where a single camera was used to supply identical images to multiple inputs of the VID systems.

Table 22 demonstrates the failure of the VID systems to detect the flaming box fires that were out of the line of sight of the cameras. The few fire alarms that did occur during the flaming box fires obscured by the cabinet were for the SigniFire system with the new model cameras. The offsite alarm of the SigniFire system effectively detected all of the flaming fires out of the line of sight. Figure 20 shows the reflections of the shielded fire behind the cabinet. As noted earlier, this offsite algorithm was designed to detect flaming fires as long as reflections from the flame are within the field of view of the camera. As can be seen in Figure 20, though

the box fire was behind the cabinet, the reflections were quite visible off of the bulkhead. The SFA smoke alarm algorithm only detected the smoke from the cardboard box fires and smoldering cable approximately half the time (i.e., with half the camera views). Both Tables 21 and 22 show that the smoke algorithm had difficulty detecting the smoke produced from the cellulosic fire regardless of the source location.

At the end of the program, Test Set 2 was repeated to include the VSD-8 system after a working replacement system was acquired. This additional testing is referred to as Test Set 2b. The data in Table 23 are the results for the SFA, SigniFire, and VSD-8 systems for Test Set 2b. The SFA and SigniFire fire algorithms failed to detect all of the flaming boxes in Location 1 for all of the camera video inputs. This inability of the systems to detect flaming boxes in Location 1 with the flame algorithms is specific to Test Set 2b; in Test Set 2, all of the video images were successfully detected by the flame algorithms. The SigniFire offsite algorithm alarmed to all flaming fires regardless of location. Both the SFA and SigniFire smoke algorithms demonstrated improved performance alarming to a majority of the flaming celluosic fires. The VSD-8 system demonstrated consistent results for the six tests. The VSD-8 system did not produce any alarms for Camera 6. The output for camera 6, attached to the DAQ, was tested and produced an alarm signal. Camera 6 was also observed in the alarm state during testing, indicated by the camera number appearing red on the VSD-8 system Graphical User Interface (GUI). However the VSD-8 system did not activate the output alarm when in the detection mode. The VSD-8 was able to produce consistent results (all the cameras alarmed except for camera 6) during three out of six tests. The camera alarm times within each test were inconsistent when compared to the other systems with alarm time standard deviations up to 80 seconds. The VSD system did demonstrate the ability to detect smoke from flaming box fires regardless of source location.

5.3 Source Repeatability

Because of the large number of variables under investigation, efforts were made to limit the variables changing during a given set of tests. One such variable was the fire source, and given the complex nature of fires, reproducing identical tests was difficult. In order to properly evaluate the effect of the source in the Test Sets, the repeatability of some selected sources was established. The repeatability of two fire sources was assessed primarily by using the spot-type smoke detectors and to a lesser degree by the activation times from the video detection systems for a strict set of parameters. The two sources selected, flaming boxes and smoldering laundry, were utilized in every test set, creating a large data set for analysis. Tests were taken from Test Sets 2, 3, 4 and 5.

Table 23 — Test Set 2b Results: Test Set 2 Reproduced to Include the VSD-8 System.

Test	Source	Location	Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6	Average	STDEV
SFA Smoke Algorithm										
260	Flaming Boxes	1	02:15	06:30	01:53	02:11	02:24	03:46	03:10	01:46
276	Flaming Boxes	1	02:35	01:53	01:49	02:59	02:06	02:50	02:22	00:30
277	Flaming Boxes	2	DNA	06:30	03:48	05:25	02:50	04:28	04:36	01:25
278	Flaming Boxes	2	02:08	01:54	01:49	02:01	01:43	02:32	02:01	00:17
279	Smoldering Laundry	2	DNA	07:43	07:40	08:07	07:35	06:51	07:35	00:28
280	Smoldering Laundry	2	07:56	06:43	05:48	06:17	06:03	05:29	06:23	00:52
SFA Fire Algorithm										
260	Flaming Boxes	1	DNA	DNA	DNA	DNA	02:50	02:20	02:35	00:21
276	Flaming Boxes	1	04:35	DNA	04:05	01:08	01:04	00:59	02:22	01:48
277	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
278	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	05:49	05:49	
279	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
280	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
SigniFire Smoke Algorithm										
260	Flaming Boxes	1	DNA	11:42	DNA	02:27	03:34	01:48	04:53	04:36
276	Flaming Boxes	1	DNA	DNA	DNA	DNA	02:47	01:21	02:04	01:01
277	Flaming Boxes	2	03:00	02:59	02:57	02:56	DNA	03:48	03:08	00:22
278	Flaming Boxes	2	02:15	02:09	02:04	02:06	01:38	01:37	01:58	00:16
279	Smoldering Laundry	2	11:01	10:48	10:58	10:52	10:21	DNA	10:48	00:16
280	Smoldering Laundry	2	04:59	04:49	04:49	04:45	04:48	03:52	04:40	00:24
SigniFire Fire Algorithm										
260	Flaming Boxes	1	02:24	00:34	02:14	02:04	01:08	00:32	01:29	00:51
276	Flaming Boxes	1	DNA	DNA	DNA	DNA	00:56	00:56	00:56	00:00
277	Flaming Boxes	2	DNA	01:24	01:29	01:25	01:11	01:14	01:21	00:08
278	Flaming Boxes	2	DNA	DNA	DNA	DNA	00:32	00:28	00:30	00:03
279	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
280	Smoldering Laundry	2	DNA	DNA	DNA	13:16	12:22	12:21	12:40	00:31
SigniFire Offsite Algorithm										
260	Flaming Boxes	1	03:42	02:36	03:48	03:50	03:13	03:23	03:25	00:28
276	Flaming Boxes	1	01:26	01:34	01:30	01:30	01:31	01:24	01:29	00:04
277	Flaming Boxes	2	01:26	01:25	01:27	01:32	01:26	01:22	01:26	00:03
278	Flaming Boxes	2	01:56	01:55	02:02	02:07	02:05	02:01	02:01	00:05
279	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
280	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA	DNA	
VSD-8 Smoke Algorithm										
260	Flaming Boxes	1	DNA	DNA	DNA	DNA	DNA	NA	DNA	
276	Flaming Boxes	1	01:29	00:48	00:55	01:24	01:34	NA	01:14	00:21
277	Flaming Boxes	2	01:36	DNA	01:46	DNA	01:52	NA	01:45	00:08
278	Flaming Boxes	2	02:01	01:41	02:01	04:31	01:50	NA	02:25	01:11
279	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	NA	DNA	
280	Smoldering Laundry	2	04:51	04:33	04:36	04:29	04:00	NA	04:30	00:19

Unlike the VID systems, the spot-type smoke detectors were inherently unaffected by many of the variables that were studied in this test series to assess their impact on the VID systems. These variables include, the light level, background colors, and camera settings. Therefore, it was expected that averaging the activation times of the smoke detectors and calculating the standard deviation would provide a reasonable assessment of the repeatability of a particular fire source at a given location. Since lighting conditions and camera settings affect the VID systems, only tests with optimized cameras and 14 Fc light levels were used to establish a measure of the source repeatability.

Table 24 through Table 27 present the averaged activation times and standard deviations for the Notifier and EST smoke detectors exposed to the flaming box and smoldering laundry fires. The average times and standard deviations are listed next to the number of tests used in calculating the average and standard deviation over the total number of tests for the specific source and location. The number of tests used varied, depending on how many detectors alarmed for a given set of tests with a specific source and source location. The flaming fires were found to be repeatable with detector activation times within 28 seconds for the Notifier ionization smoke detectors as seen in Tables 24. The alarm times used to establish the

repeatability are the times from the closest detector bay to the source. Bay 5 was the closest bay to both Location 1 and Location 2. The smoldering laundry source was less repeatable, with alarm time standard deviations of 394 seconds for Notifier ionization detectors and 382 seconds for Notifier photoelectric detectors, due to the nature of the smoldering combustion. The Notifier photoelectric detectors were not used to calculate the repeatability of flaming box fire due to the low activation rate.

Table 24 — Average Notifier Ionization Alarm Time (min:sec) for the Flaming Boxes and Smoldering Laundry Sources at Source Locations 1 and 2

Source	Location		Notifier Ion Bay 5	Number of tests
Flaming Boxes	1	Average	02:09	22/26
Flaming Boxes	1	STDEV	00:27	
Source	Location		Notifier Ion Bay 5	
Smoldering Laundry	1	Average	13:41	8/11
Smoldering Laundry	1	STDEV	06:07	
Source	Location		Notifier Ion Bay 5	
Flaming Boxes	2	Average	01:24	20/23
Flaming Boxes	2	STDEV	00:28	
Source	Location		Notifier Ion Bay 5	
Smoldering Laundry	2	Average	17:12	10/15
Smoldering Laundry	2	STDEV	06:34	

Table 25 — Average Notifier Photoelectric Detector Alarm Times (min:sec) for the Flaming Boxes and Smoldering Laundry Sources at Source Locations 1 and 2

Source	Location		Notifier Photo Bay 5	Number of tests
Flaming Boxes	1	Average	02:59	2/26
Flaming Boxes	1	STDEV	00:35	
Source	Location		Notifier Photo Bay 5	
Smoldering Laundry	1	Average	14:20	8/11
Smoldering Laundry	1	STDEV	05:50	
Source	Location		Notifier Photo Bay 5	
Flaming Boxes	2	Average	02:16	5/23
Flaming Boxes	2	STDEV	00:16	
Source	Location		Notifier Photo Bay 5	
Smoldering Laundry	2	Average	17:15	14/15
Smoldering Laundry	2	STDEV	06:22	

The flaming fires were found to be less repeatable with the EST detector activation times. Standard deviations of 64 to 73 seconds were recorded for the EST ionization smoke detectors when detecting flaming boxes, Table 26. As shown in Table 27, the EST photoelectric detectors only alarmed to one of the flaming box fires out of 49 tests; demonstrating a consistent lack of response. The smoldering laundry source was less repeatable with alarm time standard deviations of 570 seconds for EST ionization and 731 seconds for EST photoelectric.

Table 26 — Average EST Ionization Alarm Times (Min:Sec) for the Flaming Boxes and Smoldering Laundry Sources at Source Locations 1 and 2

Source	Location		EST Ion Bay 5	Number of tests
Flaming Boxes	1	Average	02:35	26/26
Flaming Boxes	1	STDEV	01:04	
Source	Location		EST Ion Bay 5	
Smoldering Laundry	1	Average	16:58	7/11
Smoldering Laundry	1	STDEV	09:30	
Source	Location		EST Ion Bay 5	
Flaming Boxes	2	Average	02:30	21/23
Flaming Boxes	2	STDEV	01:13	
Source	Location		EST Ion Bay 5	
Smoldering Laundry	2	Average	12:19	14/15
Smoldering Laundry	2	STDEV	05:54	

Table 27 — Average EST Photoelectric Detector Alarm Times (min:sec) for the Flaming Boxes and Smoldering Laundry Sources at Source Locations 1 and 2

Source	Location		EST Photo Bay 5	Number of tests
Flaming Boxes	1	Average	02:49	1/26
Flaming Boxes	1	STDEV		
Source	Location		EST Photo Bay 5	
Smoldering Laundry	1	Average	24:42	8/11
Smoldering Laundry	1	STDEV	12:11	
Source	Location		EST Photo Bay 5	
Flaming Boxes	2	Average		0/23
Flaming Boxes	2	STDEV		
Source	Location		EST Photo Bay 5	
Smoldering Laundry	2	Average	09:14	15/15
Smoldering Laundry	2	STDEV	02:25	

For the smoldering laundry and flaming box fires, the EST and Notifier ionization detectors alarmed to substantially more of the flaming fires and to a comparable number of the smoldering fires than the photoelectric detectors. The EST ionization detectors alarmed in a few more fires than the Notifier ionization detectors while the Notifier Photoelectric detectors alarmed in slightly more fires than the EST photoelectric detectors. As noted in the setup, the default sensitivity settings for the Notifier detectors were about mid-range, whereas the EST defaults are the least sensitive settings.

The video detection systems were also used as a means to judge the repeatability of the test sources. All tests using the optimized camera settings at Location 1, a light level of 14 Fc, and source Location 1 and Location 2 were compared to determine source repeatability. The alarm times for the SFA and SigniFire systems were averaged for the constant set of conditions. The results are presented in Tables 28 and 29. The results reflect the performance of each camera model. On a percentage basis, neither the old camera nor the new camera models yielded consistently more alarms or faster alarms. The flaming box fires were again the most repeatable with the smoldering laundry source varying slightly more. Compared to the spot-type smoke detectors, the VID systems have shorter alarm times and smaller alarm time standard deviations for the smoldering laundry sources. This demonstrates the ability of the VID systems to detect the slow moving smoke before it reaches the spot-type detectors, thus reducing the alarm time and the deviations in responses occurring during smoke transport.

To evaluate the repeatability of the sources, only selected comparisons of the data of Tables 28 and 29 were used. For example, to compare the flaming box fires with the flame algorithms, only flaming fires conducted in the field of view of the camera were used, since the flame algorithms were not designed to detect obscured fires or smoke sources. This approach eliminated the larger deviations that were not characteristic of the particular source repeatability. The SFA system produced smoke alarm deviations from the smoldering laundry fires as low as 70 seconds and as high as 321 seconds. The SFA fire algorithm for flaming boxes at Location 1 were detected within a standard deviation of less than 45 seconds. The SigniFire system produced fire alarm with standard deviations of 55 seconds or less for flaming box fires at Location 1. Offsite alarm standard deviations were slightly higher with a 63 second standard deviation for flaming fire at Location 1 and 112 second standard deviation at Location 2. The SigniFire smoke alarm produced the best alarm deviations for smoldering fires (83 seconds) with the limited set of data available. The data was limited because the SigniFire smoke algorithm was under development at the start of testing.

Table 28 — Average SFA Smoke and Fire Alarm Times (min:sec) for the New (SSC-DC393) and Old (SSC-DC14) Model Sony Cameras Set at Optimum Conditions with 14 Fc of Light. Flaming Boxes and Smoldering Laundry Sources at Locations 1 and 2 (noted in parentheses).

	Smoke		Smoke	
Source (location)	Old	Number of Tests	New	Number of Tests
Flaming Box (1)	03:29		03:44	
Standard Deviation	01:35	17/27	02:13	12/19
Smoldering Laundry (1)	08:18		07:57	
Standard Deviation	05:21	11/19	04:27	8/11
Flaming Box (2)	04:29		04:36	
Standard Deviation	01:56	15/35	02:11	13/23
Smoldering Laundry (2)	05:34		06:25	
Standard Deviation	01:32	8/8	01:10	4/8
	Fire		Fire	
Source (location)	Old	Number of Tests	New	Number of Tests
Flaming Box (1)	03:00		02:29	
Standard Deviation	00:39	27/27	00:43	17/19
Smoldering Laundry (1)	14:19		14:08	
Standard Deviation	09:07	10/19	07:25	7/11
Flaming Box (2)	DNA		DNA	
Standard Deviation		0/35		0/23
Smoldering Laundry (2)	DNA		DNA	
Standard Deviation		0/8		0/8

Table 29 — Average Signifire Off-Site, Smoke and Fire Alarm Times (Min:Sec) for the New (SSC-DC393) and Old (SSC-DC14) Model Sony Cameras Set at Optimum Conditions with 14 Fc of Light. Flaming Boxes and Smoldering Laundry Sources at Locations 1 and 2

	Smoke		Smoke	
Source (location)	Old	Number of Tests	New	Number of Tests
Flaming Boxes (1)	03:25		03:39	
Standard Deviation	01:15	5/27	00:57	4/27
Smoldering Laundry (1)	04:06		04:17	
Standard Deviation		1/19		1/11
Flaming Boxes (2)	06:58		DNA	
Standard Deviation		1/35		0/23
Smoldering Laundry (2)	05:57		06:18	
Standard Deviation	01:23	6/8	01:01	6/8
	Fire		Fire	
Source (location)	Old	Number of Tests	New	Number of Tests
Flaming Boxes (1)	02:01		01:45	
Standard Deviation	00:49	27/27	00:55	19/19
Smoldering Laundry (1)	14:33		15:18	
Standard Deviation	08:07	13/19	08:21	5/11
Flaming Boxes (2)	05:54		05:42	
Standard Deviation	00:33	2/35	01:48	7/23
Smoldering Laundry (2)	DNA		DNA	
Standard Deviation		0/8		0/8
	Offsite		Offsite	
Source (location)	Old	Number of Tests	New	Number of Tests
Flaming Boxes (1)	02:30		02:03	
Standard Deviation	00:52	27/27	01:03	19/19
Smoldering Laundry (1)	07:12		06:55	
Standard Deviation	06:57	5/19	07:07	5/11
Flaming Boxes (2)	04:31		03:36	
Standard Deviation	01:22	35/35	01:52	23/23
Smoldering Laundry (2)	22:00		00:41	
Standard Deviation		1/8		1/8

Examining the source repeatability using the spot-type smoke detectors and VID system results has established a minimum standard deviation needed for comparison in the following test sets. The source repeatability is necessary for comparing test-to-test results when compartment conditions are varied; such as in Test Set 3 and Test Set 4. The minimum detector alarm standard deviations should only be used for their respective system (i.e., EST detector to EST detector, and SFA algorithm to SFA algorithm). Table 30 lists the calculated alarm deviation for smoldering laundry and flaming boxes for each of the detectors. The values in Table 30 represent the maximum standard deviations from Tables 24 to 29 for appropriate source/detection system comparisons. As noted for Tables 28 and 29, the standard deviation between alarms for the flame algorithms only includes cases where the fire was within the field of view. For the SigniFire offsite algorithm, only fire tests with the source at Location 2 (out of the camera FOV) were used in calculating the standard deviations. The smoke algorithms used all fires regardless of the source location.

Table 30 — Each VID and Spot-Type Detection System is Listed with Their Respective Alarm Time Deviations (In Seconds) for Flaming Box Fires and Smoldering Laundry Fires

Detection System Alarm Time Standard Deviations (seconds)		
Detection System	**Source**	
	Flaming Boxes	**Smoldering Laundry**
SFA Fire	43	547
SFA Smoke	133	321
SigniFire Offsite	112	427
SigniFire Fire	108	501
SigniFire Smoke	75	83
EST Ion	73	570
EST Photo	N/A	731
Notifier Ion	30	334
Notifier Photo	35	357

* NA = Not Available because there were no alarms

5.4 Test Set 3

Having established that the six collocated cameras produced fairly consistent alarms for the flaming box fires in Test Set 2 (see Section 5.2), the illumination levels within the compartment were then varied keeping all other conditions constant. The SigniFire smoke alarm was not available in the early stages of testing, so results are presented only for the red light conditions that were conducted in the later portions of Test Set 3. Limited data was collected for Test Set 3 because Test Set 4 expanded on Test Set 3 increasing the variables and repeating many of the tests that were proposed for Test Set 3.

Table 31 presents the SigniFire offsite alarms for flaming boxes at Location 1 and Location 2 for the 14 Fc illumination level and red illumination. In general, changing from the 14 Fc white lighting to the red lighting in the compartment resulted in faster offsite fire alarms, particularly for the cases in which the fire was obstructed from the cameras field of view at Source Location 2. For the flaming box fires at Location 2, the offsite algorithm alarmed approximately 2 to 3 minutes faster for the red illumination, which yielded darker video images than the 14 Fc white illumination. For the flaming box fires at Location 1 (in the direct field of view), the average offsite algorithm alarm time was approximately 1 minute faster for the red illumination. The average alarm times during the red illumination for flaming boxes at Location 1 have large standard deviations due to Test 86 that produced very fast alarm times. The data was re-examined along with the video and alarm logs and found to be correct. As shown below for the other fire algorithms, the darker background of the red illumination generally yields improved fire detection.

Table 31 — Signifire Offsite Algorithm Alarm Times to Flaming Boxes at Location 1 and Location 2 for 14 Fc White Light and Red Illumination

Test	Source	Location	Illumination (Fc)	SigniFire Offsite Algorithm					
				Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6
19	Flaming Boxes	1	14	03:17	03:08	03:07	03:04	03:04	03:01
20	Flaming Boxes	1	14	03:06	03:04	02:49	03:03	03:07	02:52
21	Flaming Boxes	1	14	01:49	01:48	01:46	02:02	01:47	01:45
22	Flaming Boxes	1	14	02:47	02:45	02:25	02:44	02:47	02:41
			Average	02:45	02:41	02:32	02:43	02:41	02:35
			STDEV	00:39	00:37	00:35	00:29	00:37	00:34
85	Flaming Boxes	1	Red	02:46	02:43	02:47	02:44	02:45	02:46
86	Flaming Boxes	1	Red	00:33	00:33	00:35	00:30	00:24	00:25
			Average	01:40	01:38	01:41	01:37	01:35	01:36
			STDEV	01:34	01:32	01:33	01:35	01:40	01:40
10	Flaming Boxes	2	14	03:51	04:03	03:50	04:01	03:47	03:46
16	Flaming Boxes	2	14	03:27	03:27	03:28	03:27	03:28	03:28
23	Flaming Boxes	2	14	06:09	07:50	06:20	07:20	05:14	06:58
24	Flaming Boxes	2	14	05:40	05:56	05:44	05:37	05:36	05:32
25	Flaming Boxes	2	14	04:28	04:48	04:32	04:28	04:26	04:32
26	Flaming Boxes	2	14	05:37	06:01	06:08	06:00	05:42	05:42
			Average	04:52	05:21	05:00	05:09	04:42	05:00
			STDEV	01:06	01:35	01:14	01:26	00:57	01:19
87	Flaming Boxes	2	Red	01:34	01:29	01:34	01:28	01:27	01:27
88	Flaming Boxes	2	Red	03:40	03:37	03:39	03:37	01:55	01:56
			Average	02:37	02:33	02:37	02:33	01:41	01:42
			STDEV	01:29	01:31	01:28	01:31	00:20	00:21

Table 32 presents the alarm times for the SigniFire fire algorithm for the flaming boxes at Location 1 and Location 2 for the 14 Fc illumination level and red illumination. Similar to the SigniFire offsite algorithm, the flame algorithm also showed improved detection performance under red illumination over the 14 Fc white light. With the fire at Source Location 1 in the direct line of sight of the cameras, the average alarm times indicate a improved performance under red illumination. Again the results may be skewed due to test 86 that produced extremely low activation times. When the fires are obstructed from the cameras at Source Location 2, the red illumination appears to improve the performance of the SigniFire fire algorithm.

Table 33 presents the SigniFire smoke algorithm alarm times for flaming boxes at Location 1 and Location 2 for the red illumination. The SigniFire smoke algorithm was not available at the beginning of testing, so no comparison can be made to the tests conducted at 14 Fc. The smoke algorithm alarmed for all of the camera images (except Camera 6) when the fire was obstructed, but only alarmed for two of the twelve images obtained in the two tests when the source was in the direct line of sight of the camera. As noted earlier, the smoke production from the flaming boxes varied considerably from test to test relative to the detection limits of the smoke alarm algorithms. Therefore, the trends observed in Table 33 need to be confirmed over a larger database of tests in order to be stated with confidence.

Table 32 — Signifire Fire Algorithm Alarm Times to Flaming Boxes at Location 1 and Location 2 For 14 Fc and Red Illumination

Test	Source	Location	Illumination (Fc)	SigniFire Fire Algorithm					
				Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6
19	Flaming Boxes	1	14	02:50	02:44	02:44	02:53	02:34	02:36
20	Flaming Boxes	1	14	02:58	02:51	02:39	02:35	02:40	02:47
21	Flaming Boxes	1	14	01:47	01:43	01:38	01:40	01:30	01:45
22	Flaming Boxes	1	14	02:32	02:22	02:15	02:16	02:17	02:19
			Average	02:32	02:25	02:19	02:21	02:15	02:22
			STDEV	00:32	00:31	00:30	00:31	00:32	00:27
85	Flaming Boxes	1	Red	02:41	02:43	02:41	02:42	02:55	02:54
86	Flaming Boxes	1	Red	00:10	00:14	00:14	00:13	01:23	01:06
			Average	01:26	01:29	01:28	01:28	02:09	02:00
			STDEV	01:47	01:45	01:44	01:45	01:05	01:16
10	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	07:19	DNA
16	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	04:23	06:43
23	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	07:39	DNA
24	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
25	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
26	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
			Average	DNA	DNA	DNA	DNA	06:27	06:43
			STDEV					01:48	
87	Flaming Boxes	2	Red	DNA	06:36	DNA	05:50	DNA	06:26
88	Flaming Boxes	2	Red	DNA	DNA	07:56	06:39	DNA	DNA
			Average	DNA	06:36	07:56	06:15	DNA	06:26
			STDEV				00:35		

Table 33 — Signifire Smoke Algorithm Response to Flaming Boxes at Location 1 and Location 2 Under Red Illumination

Test	Source	Location	Illumination (Fc)	SigniFire Smoke Algorithm					
				Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6
85	Flaming Boxes	1	Red	03:10	DNA	03:11	DNA	DNA	DNA
86	Flaming Boxes	1	Red	DNA	DNA	DNA	DNA	DNA	DNA
			Average	03:10	DNA	03:11	DNA	DNA	DNA
			STDEV						
87	Flaming Boxes	2	Red	04:24	04:20	04:25	04:15	04:01	DNA
88	Flaming Boxes	2	Red	04:54	04:53	04:56	04:50	05:18	DNA
			Average	04:39	04:37	04:41	04:33	04:40	DNA
			STDEV	00:21	00:23	00:22	00:25	00:54	DNA

Table 34 presents the SFA smoke alarms for flaming boxes at Location 1 and Location 2 for the 14 Fc illumination level and red illumination. Similar to the SigniFire smoke algorithm, the SFA smoke algorithm performed better with the red illumination, activating a larger percentage of alarms during the red illumination with quicker activation times. Camera 4 is of particular interest because of the long alarm times it produced compared to the other five cameras. The reason for this anomaly is uncertain; however, it did not occur for the other fire and smoke alarm algorithms (either the SigniFire or SFA). Therefore, the issue is specific to the SFA smoke algorithm.

Table 34 — SFA Smoke Algorithm Alarm Times to Flaming Boxes at Location 1 and Location 2 for 14 Fc and Red Illumination

				SFA Smoke Algorithm					
Test	Source	Location	Illumination (Fc)	Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6
19	Flaming Boxes	1	14	DNA	DNA	DNA	DNA	DNA	DNA
20	Flaming Boxes	1	14	04:31	04:30	04:12	04:33	04:27	04:28
21	Flaming Boxes	1	14	DNA	DNA	04:22	DNA	DNA	DNA
22	Flaming Boxes	1	14	DNA	DNA	03:49	05:27	05:17	04:02
			Average	04:31	04:30	04:08	05:00	04:52	04:15
			STDEV			00:17	00:38	00:35	00:18
85	Flaming Boxes	1	Red	01:55	01:57	02:47	08:19	01:47	02:04
86	Flaming Boxes	1	Red	03:40	03:44	DNA	10:25	02:51	02:55
			Average	02:48	02:51	02:47	09:22	02:19	02:30
			STDEV	01:14	01:16		01:29	00:45	00:36
10	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
16	Flaming Boxes	2	14	DNA	07:08	DNA	DNA	04:21	05:44
23	Flaming Boxes	2	14	06:43	07:09	04:34	06:30	06:10	06:09
24	Flaming Boxes	2	14	03:18	DNA	DNA	DNA	09:33	DNA
25	Flaming Boxes	2	14	DNA	DNA	DNA	04:05	03:50	03:55
26	Flaming Boxes	2	14	DNA	04:49	04:45	04:55	04:45	04:46
			Average	05:00	06:22	04:39	05:10	05:44	05:08
			STDEV	02:25	01:21	00:08	01:14	02:18	01:00
87	Flaming Boxes	2	Red	04:08	04:43	04:40	09:38	04:06	03:26
88	Flaming Boxes	2	Red	04:46	04:32	04:42	08:36	03:13	DNA
			Average	04:27	04:38	04:41	09:07	03:40	03:26
			STDEV	00:27	00:08	00:01	00:44	00:37	DNA

Table 35 presents the SFA fire alarms for flaming boxes at Location 1 and Location 2 for the 14 Fc illumination level and red illumination. The results demonstrate the difficulty the SFA fire algorithm had detecting flaming fires obscured from the cameras line of sight (i.e., Location 2). When the flaming source was moved into the cameras line of sight, the SFA fire algorithm was able to produce an alarm for almost all cameras. Changing the illumination from 14 Fc of white light to red illumination increases the ability of the SFA fire algorithm to detect flaming fires, this is demonstrated by a decrease in alarm times. The red illumination did affect the ability of the SFA fire algorithm to detect flaming sources when using the new model cameras (Camera 5 and 6), resulting in no alarms whereas the older model cameras did alarm.

Test Set 3 identified distinct differences in detection capabilities dependant of camera model and illumination level. The VID algorithms generally followed the same trend apparent through out testing; flame algorithms alarm to line of sight flaming fires and smoke algorithms react to visible smoke. It is clear from the results in Test Set 3 that the red illumination has an affect on the activation time and camera model. The red illumination generally increases the ability to detect smoke and flames within the compartment, but as demonstrated with the SFA flame algorithm, the red illumination can also inhibit detection depending on camera model.

Table 35 — SFA Fire Algorithm Alarm Times to Flaming Boxes at Location 1 and Location 2 For 14 Fc and Red Illumination

				SFA Fire Algorithm					
Test	Source	Location	Illumination (Fc)	Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6
19	Flaming Boxes	1	14	03:33	03:22	03:25	03:30	03:22	03:25
20	Flaming Boxes	1	14	03:55	03:32	03:36	03:18	03:30	03:10
21	Flaming Boxes	1	14	02:33	02:35	02:31	02:23	02:08	02:12
22	Flaming Boxes	1	14	03:29	03:23	03:08	03:05	03:10	02:56
			Average	03:22	03:13	03:10	03:04	03:02	02:56
			STDEV	00:35	00:26	00:28	00:29	00:37	00:31
85	Flaming Boxes	1	Red	03:01	03:03	03:12	02:59	DNA	DNA
86	Flaming Boxes	1	Red	00:55	01:05	01:02	01:08	DNA	DNA
			Average	01:58	02:04	02:07	02:04	DNA	DNA
			STDEV	01:29	01:23	01:32	01:18		
10	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
16	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
23	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
24	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
25	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
26	Flaming Boxes	2	14	DNA	DNA	DNA	DNA	DNA	DNA
			Average	DNA	DNA	DNA	DNA	DNA	DNA
			STDEV						
87	Flaming Boxes	2	Red	DNA	DNA	DNA	DNA	DNA	DNA
88	Flaming Boxes	2	Red	DNA	DNA	DNA	DNA	DNA	DNA
			Average	DNA	DNA	DNA	DNA	DNA	DNA
			STDEV						

5.5 Test Set 4 Results

The settings of the six cameras were adjusted to yield cameras with optimal, dark contrast, light contrast, and out of focus conditions, as noted in Table 36. The settings were configured at the 14 Fc illumination level and were not reset or adjusted with changes to the test compartment illumination level. This meant that when Camera 2 was set to yield a light contrast image at 14 Fc and the illumination level was lowered in subsequent tests to 7 Fc, it was still referred to as light contrast even though the combination of the lower light level and the initial light contrast setting may have created the optimal camera setting with the new illumination level. Figure 22 shows a video image for each of the cameras with the different settings listed in Table 36. Section 4.3.3 provides a description of the variations in camera settings.

Table 36 — Camera Setting Corresponding to the Camera Number

Camera	Setting	Model Number
1	Optimum	SSC-DC14
2	Light Contrast	SSC-DC14
3	Dark Contrast	SSC-DC14
4	Out of Focus	SSC-DC14
5	Optimum	SSC-DC393
6	Dark Contrast	SSC-DC393

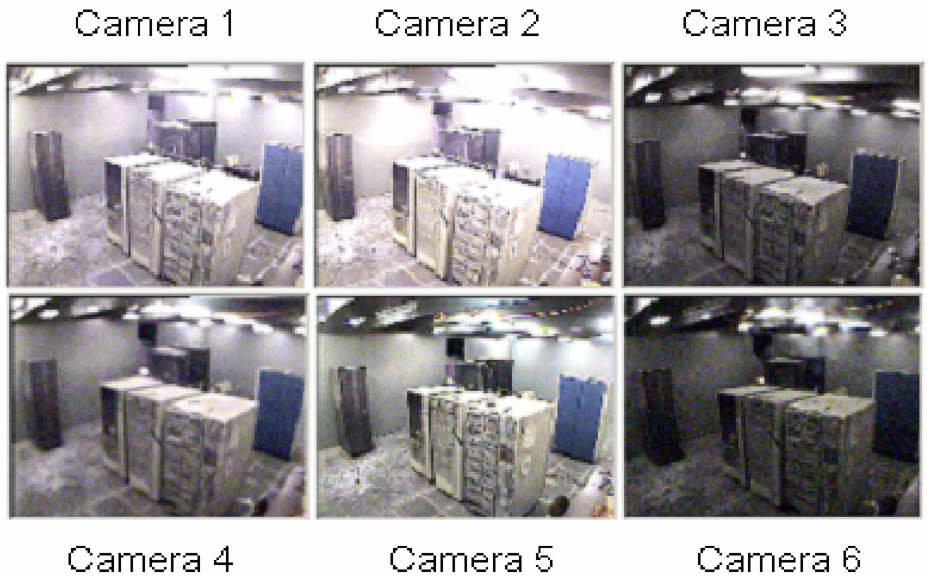

Fig. 22 — Varied camera images for the six collocated cameras at Location 1
(Camera setting in Table 36)

The illumination levels in the compartment were varied between tests to achieve four conditions: 7, 14, and 28 foot-candles of white light and red illumination using the 14 Fc setup (i.e., the 14 Fc light fixtures with red sleeves over the bulbs). Tables 37 through 44 present the alarm time results for the SigniFire and SFA systems. Due to the hardware output problems with the VSD-8 system, the VID system could not be used for Test Set 4 since the response of individual collocated cameras could not be identified. Test Set 4 is divided into sub-sections for each system and alarm algorithm to determine algorithm bias toward an illumination level or camera setting. Bias was determined on a test by test basis within a given illumination level and source for the camera setting and a test set to test set basis for illumination level.

5.5.1 SFA Smoke Algorithm

Table 37 lists the SFA smoke algorithm alarms for smoldering laundry at Location 2 with varying illumination levels. The Table demonstrates that the SFA smoke algorithm yielded longer alarm times with the dark contrast and out of focus cameras compared to the optimal and light contrast cameras, independent of camera model. The red illumination produced the least alarm activations with only two cameras detecting the smoke the light contrast and the new model with optimal settings. During the red illumination the light contrast setting resulted in faster alarm times than the new model Sony with optimal settings. In general, for all of the lighting conditions, the SFA smoke algorithm results indicate that for a smoldering fire it is better to have cameras adjusted toward light contrast and brighter illumination levels than dark contrast and lower illumination levels.

Table 37 — SFA Smoke Alarm Times (min:sec) for Smoldering Laundry Fires in Location 2 with Various Camera Settings and Light Levels

SFA Smoke Algorithm							
Test	Illumination (Fc)	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized (new)	Camera 6 Dark Contrast (new)
83	28	04:18	04:20	05:57	06:09	04:16	05:33
64	14	07:13	06:07	08:52	07:40	06:53	DNA
65	14	07:19	DNA	08:39	08:41	07:09	09:45
	Average	07:16	06:07	08:46	08:11	07:01	
70	7	10:44	08:47	11:18	11:12	10:12	DNA
71	7	08:44	04:46	10:23	09:31	05:13	13:08
	Average	09:44	06:47	10:51	10:22	07:43	
76	Red	DNA	02:18	DNA	DNA	05:17	DNA
77	Red	DNA	05:15	DNA	DNA	07:50	DNA
	Average		03:47			06:34	

Table 38 shows the SFA smoke alarm results for flaming box fires at Location 1. In general, the repeatability of the smoke alarm times for a given light level and camera setting was poor, with variations in time as high as a factor of three and cases in which alarms did and did not occur for repeat tests. As presented previously, the VID systems had difficulty in detecting the flaming box fires because the low smoke yield that was hard to discern in the camera video image Despite this variability, a few trends are still apparent. The SFA system had difficulty detecting smoke for the flaming boxes when the camera settings were set out of focus or set to dark contrast (generally fewer alarms occurred). Though these results are not as conclusive as for the smoldering laundry tests, they are fairly consistent. As observed with the smoldering tests, the red illumination created the greatest challenge; alarms were obtained only for the old camera with the light contrast setting and the new camera with optimal settings. These results again emphasize that in focus, optimal to light contrast camera settings are preferable than dark images for detecting smoke with the VID system smoke algorithms. In fact, the dark contrast and out of focus settings resulted in the system not alarming.

The SFA smoke algorithm results for flaming boxes at Location 2 and smoldering laundry at Location 1 are not presented here because of the similarity in results to flaming boxes at Location 1 and smoldering laundry at Location 2. The complete set of results is included on the attached CD.

5.5.2 SFA Fire Algorithm

Table 39 presents the SFA fire alarm times for flaming box fires in Location 1 (in the direct line of sight of the camera) with various camera settings and light levels. Given the rather fast alarm times (~1.5 to 4 minutes), it is difficult to discern clear trends in the data relative to the variation in camera settings. At 28 Fc of light, no single camera setting appears better than another. This trend is fairly consistent for illumination levels of 14 Fc and 7 Fc. The main exception for all the light levels, particularly for the new camera model, is that there is a slight indication of improved performance for the SFA flame algorithm with darker contrast. With the red illumination condition, the new model cameras did not yield a SFA fire alarm. This supports the similar observations seen in Test Set 3 for the SFA fire algorithm in Tests 85 and 86 (see

Table 35). This inability of the SFA flame algorithm to detect flaming fires under red illumination may be due to differences in the features of the camera model discussed in Section 4.3.3, Video. With the old model (Cameras 1 to 4) that did cause an alarm during the red illumination, there was little effect on the alarm time due to the contrast settings. The SFA Fire algorithm for flaming boxes at Location 2 was not included because of the difficulty of the flame algorithm to detect obscured fires.

Table 38 — SFA Smoke Alarm Times (min:sec) for Flaming Box Fires in Location 1 with Various Camera Settings and Light Levels*

SFA Smoke Algorithm							
Test	Illumination (Fc)	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized (new)	Camera 6 Dark Contrast (new)
78	28	05:35	03:11	08:04	DNA	03:33	DNA
80	28	04:04	04:00	08:18	DNA	04:17	DNA
	Average	04:49	03:35	08:11		03:55	
58	14	07:00	DNA	06:25	06:45	06:58	05:33
59	14	08:58	06:36	02:38	07:49	08:12	08:38
60	14	DNA	07:21	DNA	DNA	DNA	DNA
	Average	07:59	06:58	04:31	07:17	07:35	07:05
66	7	02:09	01:58	DNA	DNA	02:08	DNA
67	7	07:39	04:59	DNA	DNA	07:53	DNA
	Average	04:54	03:29			05:01	
74	Red	DNA	04:37	DNA	DNA	07:12	DNA
75	Red	DNA	03:56	DNA	DNA	03:02	DNA
	Average		04:17			05:07	

* Test number 79 is missing from the table due to a power surge resulting in a shut down of the SFA system

Table 39 — SFA Fire Alarm Times (min:sec) for Flaming Box Fires in Location 1 (In the Line of Sight) with Various Camera Settings and Light Levels*

SFA Fire Algorithm							
Test	Illumination (Fc)	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized (new)	Camera 6 Dark Contrast (new)
78	28	01:32	01:50	01:42	01:35	01:47	01:00
80	28	02:43	01:49	02:37	02:28	02:36	02:00
	Average	02:07	01:50	02:09	02:01	02:11	01:30
58	14	03:45	03:03	02:44	02:49	02:50	02:07
59	14	03:49	04:01	03:09	01:51	02:47	01:41
60	14	02:20	02:38	02:40	02:39	02:14	02:13
	Average	03:18	03:14	02:51	02:26	02:37	02:00
66	7	01:54	04:07	01:52	01:24	02:12	01:11
67	7	02:00	02:03	02:18	02:07	01:54	01:42
	Average	01:57	03:05	02:05	01:46	02:03	01:27
74	Red	02:43	02:42	03:00	02:07	DNA	DNA
75	Red	02:05	01:49	02:09	01:47	DNA	DNA
	Average	02:24	02:16	02:35	01:57	DNA	DNA

*Test number 79 is missing from the table due to a power surge resulting in a shut down of the SFA system

5.5.3 SigniFire Smoke Algorithm

Table 40 lists the SigniFire smoke alarm times for various camera settings and illumination levels for smoldering laundry fires at Location 2. Camera 6, the new model Sony with dark

contrast settings, did not yield any SigniFire smoke alarms during any of the smoldering laundry fires. The red illumination caused the greatest challenge to the system with only Camera 2 and Camera 5 activating smoke alarms, (the light contrast old model and the optimized new model cameras, respectively). The dark contrast camera repeatedly responded slower than any other camera setting while the bright contrast setting responded faster. The new and old model response was similar to each other, with exception to the red illumination. Overall the light contrast and optimized cameras responded the quickest.

Table 40 — Signifire Smoke Alarms for Smoldering Laundry at Location 2 for the Various Camera Settings and Light Levels

SigniFire Smoke Algorithm							
Test	Illumination (Fc)	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized (new)	Camera 6 Dark Contrast (new)
83	28	05:19	05:21	05:26	05:18	05:35	DNA
84	28	08:07	08:03	09:11	08:43	08:01	DNA
	Average	06:43	06:42	07:18	07:00	06:48	DNA
64	14	07:41	07:40	08:33	07:56	07:38	DNA
65	14	07:44	06:42	10:21	10:06	07:28	DNA
	Average	07:42	07:11	09:27	09:01	07:33	DNA
70	7	09:07	08:33	11:17	09:05	09:08	DNA
71	7	05:47	05:13	09:55	07:17	05:37	DNA
	Average	07:27	06:53	10:36	08:11	07:23	DNA
76	Red	DNA	09:29	DNA	DNA	09:58	DNA
77	Red	DNA	09:35	DNA	DNA	17:34	DNA
	Average	DNA	09:32	DNA	DNA	13:46	DNA

Table 41 shows the SigniFire smoke alarm results for flaming box fires at Location 1. In general, the repeatability of the smoke alarm times for a given light level and camera setting was poor, with variations in time as high as a factor of three and cases in which alarms did and did not occur for repeat tests. This poor performance is due to the difficulty of detecting smoke from the cellulosic flaming fires that can be almost invisible to the camera and the naked eye. Despite this variability, a few trends are still apparent. The SigniFire system had difficulty detecting smoke for the flaming boxes when the camera settings were set out of focus or set to dark contrast (generally fewer alarms occurred). Though these results are not as conclusive as for the smoldering laundry tests, they are fairly consistent. As observed with the smoldering tests, the red illumination created the greatest challenge; alarms were obtained only for the old camera with the light contrast setting. These results again emphasize that in focus, optimal to light contrast camera settings are preferable than dark images for detecting smoke with the VID system smoke algorithms.

Table 41 — Signifire Smoke Alarms for Flaming Boxes at Location 1 for the Various Camera Settings and Light Levels

SigniFire Smoke Algorithm							
Test	Illumination (Fc)	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized	Camera 6 Dark
78	28	03:16	03:05	02:33	03:01	03:14	DNA
79	28	08:32	04:01	DNA	DNA	04:52	DNA
80	28	03:25	03:59	03:29	03:55	04:08	DNA
	Average	05:04	03:42	03:01	03:28	04:05	DNA
58	14	01:18	01:02	02:24	02:10	02:17	DNA
59	14	04:26	04:19	04:33	DNA	04:26	DNA
60	14	04:14	03:50	03:57	03:57	04:04	DNA
	Average	03:19	03:04	03:38	03:04	03:36	DNA
66	7	03:12	02:51	03:06	DNA	03:13	03:12
67	7	DNA	03:18	DNA	03:02	DNA	DNA
	Average	03:12	03:05	03:06	03:02	03:13	03:12
74	Red	DNA	03:07	DNA	DNA	DNA	DNA
75	Red	DNA	04:31	DNA	DNA	DNA	DNA
	Average	DNA	03:49	DNA	DNA	DNA	DNA

The SigniFire smoke algorithm results for flaming boxes at Location 2 and smoldering laundry at Location 1 were not included because of the similarity in results to flaming boxes at Location 1 and smoldering laundry at Location 2.

5.5.4 SigniFire Flame Algorithm

Table 42 presents the SigniFire fire alarm times for flaming box fires in the direct line of sight of the camera (Location 1) with various camera settings and light levels. Given the relatively large deviations associated with the fast alarm times, it is difficult to discern clear trends in the data relative to the variation in camera settings. At the 28 Fc illumination level, no single camera setting appears better than another. This trend is fairly consistent for illumination levels of 14 Fc and 7 Fc and red illumination. Overall the SigniFire fire algorithm responded quickly to all the flaming fires at Location 1 independent of illumination level or the camera setting.

5.5.5 SigniFire Offsite Algorithm

Table 43 presents the SigniFire offsite algorithm alarm times for flaming box fires in Location 1 with various camera settings and light levels. At 28 Fc, the alarm times are very close for each camera and setting. There is a slight indication (Test 78 Camera 3 and Test 80 Camera 6) that a dark contrast resulted in a faster detection time of the flaming boxes fire; however, this trend was not consistent for all cases. At 14 Fc, the out of focus camera triggered an alarm first. At 7 Fc and the red illumination levels the alarm response times are quicker overall compared to the 28 and 14 Fc illumination levels. There may be a limit to benefiting from darkened images. For example, Camera 3 with a dark contrast setting and the red

illumination showed an increase in the time to detection, implying that the combination of dark contrast settings and a dark compartment can slow flame detection by becoming exceedingly dark. The flaming box fires in the line of sight of the cameras create quick alarm times for all illumination levels making it difficult to differentiate any benefit between them. Overall the SigniFire offsite algorithm responded quickly to all the flaming fires at Location 1 relatively independent of illumination level as well as camera setting.

Table 42 — Signifire Fire Alarms for Flaming Boxes at Location 1 for the Various Camera Settings and Light Levels

SigniFire Fire Algorithm							
Test	Illumination (Fc)	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized	Camera 6 Dark
78	28	03:46	00:30	00:27	00:26	00:33	00:17
79	28	03:11	02:38	01:48	00:39	01:38	00:41
80	28	00:29	00:38	00:42	00:28	00:29	00:22
	Average	02:29	01:15	00:59	00:31	00:53	00:27
58	14	01:12	00:08	01:53	00:09	00:19	DNA
59	14	00:58	01:00	01:04	00:55	00:56	00:54
60	14	00:36	00:33	02:26	00:29	00:39	00:43
	Average	00:55	00:34	01:48	00:31	00:38	00:49
66	7	00:52	01:05	00:53	00:21	00:50	00:23
67	7	00:50	01:05	02:10	00:46	00:48	00:51
	Average	00:51	01:05	01:31	00:33	00:49	00:37
74	Red	01:34	01:20	01:53	01:51	01:10	01:21
75	Red	01:15	01:03	01:20	01:04	01:03	01:10
	Average	01:25	01:12	01:37	01:28	01:07	01:16

Table 43 — Signifire Offsite Alarms for Flaming Boxes at Location 1 (In the Line of Sight) for the Various Camera Settings and Light Levels

SigniFire Offsite Algorithm							
Test	Illumination (Fc)	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized	Camera 6 Dark
78	28	02:02	02:21	01:02	01:57	01:59	01:48
79	28	03:51	03:35	03:49	03:41	03:43	03:30
80	28	02:47	02:47	02:47	02:41	02:48	00:52
	Average	02:53	02:54	02:33	02:46	02:50	02:03
58	14	02:12	02:59	02:41	01:47	02:20	N/A
59	14	01:03	03:05	03:36	01:03	01:02	01:00
60	14	02:48	02:50	02:52	00:48	02:48	02:52
	Average	02:01	02:58	03:03	01:13	02:03	01:56
66	7	00:44	00:51	00:53	00:53	00:40	00:55
67	7	00:51	00:53	02:37	00:51	00:53	02:27
	Average	00:47	00:52	01:45	00:52	00:47	01:41
74	Red	01:34	01:09	03:40	01:33	01:04	DNA
75	Red	01:16	01:22	04:02	01:23	01:10	01:22
	Average	01:25	01:16	03:51	01:28	01:07	01:22

The SigniFire offsite algorithm for smoldering fires was not included because of the difficulty for the offsite algorithm to detect smoldering sources. Since, the offsite algorithm is not designed to detect smoldering fires, it is not surprising that the system only detected 3 out of

15 cases. Although the offsite algorithm is not designed to detect fires within the field of view, it performed quite well for these tests as shown in Table 44. The alarm times were longer than obtained with the flame algorithm, which is designed for rapid detection of fires within the field of view. Therefore, these component algorithms provide complimentary performance capabilities for the SigniFire system, with the offsite algorithm serving as a backup routine for the flame algorithm.

Table 44 — Signifire Offsite Alarms for Flaming Boxes Out of the Direct Line of Sight of the Camera (Location 2) for Various Camera Settings and Light Levels

SigniFire Offsite Algorithm							
Test	Illumination (Fc)	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized (new)	Camera 6 Dark Contrast (new)
81	28	03:48	04:29	04:55	03:45	DNA	03:37
82	28	DNA	DNA	04:06	04:06	DNA	04:00
	Average	03:48	04:29	04:30	03:55	DNA	03:48
61	14	03:30	03:38	03:43	02:41	03:24	03:02
62	14	03:33	04:27	04:33	03:38	04:26	03:32
63	14	03:06	03:20	03:10	03:02	03:03	03:00
	Average	03:23	03:48	03:49	03:07	03:38	03:11
68	7	02:41	02:56	03:43	02:41	02:42	02:47
69	7	01:25	03:42	03:48	03:00	03:39	03:39
	Average	02:03	03:19	03:45	02:50	03:11	03:13
72	Red	03:22	01:45	DNA	03:41	01:46	04:01
73	Red	02:48	02:57	DNA	02:12	02:05	03:20
	Average	03:05	02:21	DNA	02:57	01:55	03:41

5.5.6 Comparison of VID system Algorithms

The SigniFire offsite algorithm generally does not respond as well as the SigniFire flame algorithm when a fire is in the line of sight, however, the SigniFire offsite algorithm responds better than the flame algorithm when the fire is at Location 2, out of the camera line of sight. The SigniFire smoke algorithm demonstrated the ability to detect visible smoke from the smoldering fires but had difficulty in detecting the transparent smoke produced from the flaming boxes. The SFA smoke algorithm had similar performance results to the SigniFire smoke algorithm for the visible smoke and the transparent smoke produced from flaming boxes. The SFA fire algorithm was able to detect flaming fires when in the line of sight of the camera. The SFA system could not detect an obscured flaming fire unless the fire produced enough smoke to be detected by the SFA smoke algorithm. Overall the systems demonstrated an ability to detect smoke and fire for numerous camera settings and lighting conditions. The dark contrast and low illumination levels were generally more conducive to detecting flaming fires while the light contrast and high illumination levels were better for detecting smoke. Although the VID systems demonstrated the ability to alarm to various camera settings and light levels, specific combinations of illumination, camera setting and VID system algorithm can produce no alarms. The SFA smoke and SigniFire smoke algorithms did not alarm to when cameras set to dark contrast were located in a compartment under red illumination with exception to the SigniFire smoke with the new model camera. The SFA flame algorithm would not produce an alarm when the new cameras were in a compartment with red illumination. The SigniFire offsite alarm did not produce alarms when the old cameras set to dark contrast were under red illumination. With exception to these relatively extreme cases, the VID systems were able to produce alarms on a rather consistent basis.

5.5.7 Test Set 4b Results

Test Set 4 was repeated at the end of the main test program to include the VSD-8 system after a replacement system was acquired. The compartment, VID systems, and camera settings were re-configured to conduct Test Set 4b. The replacement VSD-8 system was attached to the main data acquisition system and output signals were produced similar to Test Set 2b and recorded from each camera. Though alarms occurred, Camera 6 output did not produce any alarm signal. Therefore, no results are available for camera 6.

The data in Table 45 are the algorithm results for the SFA, SigniFire, and VSD-8 systems for Test Set 4b. The SFA Fire algorithm produced no alarms for the smoldering source or flaming boxes at Location 2. The SFA fire algorithm produced limited alarms for the flaming boxes at Location 1. The few alarms that did occur were from the dark contrast and optimized new model camera. This supports the earlier findings that dark conditions are more suitable for detecting flaming fires. The SFA smoke algorithm produced alarms for a majority of the camera settings and sources. The SFA smoke system demonstrated a slight bias towards the optimized cameras which produced alarm times faster than the light contrast camera. The SigniFire fire algorithm favored the dark contrast and optimized new model cameras as well as the out of focus cameras over the light contrast and optimized old model camera for detecting flaming fires. The SigniFire offsite algorithm produced mixed results with activation times too close to determine a bias toward one setting. The SigniFire smoke algorithm produced a number of alarms with relatively close activation times, however the SigniFire smoke algorithm did demonstrate a slight bias towards the light contrast and new model cameras.

Because of an internal failure of the output signaling system, the VSD-8 Camera 6 video channel did not produce any alarm output signals during the tests, although the system was known to have alarmed in some tests based on the screen display. Partly due to this failure, there was an insufficient number of alarms produced from the VSD-8 system to determine a preferred camera setting. The VSD-8 system was able to detect flaming fires at Location 1 and Location 2, however, the system had difficultly detecting the smoldering sources. This is unusual when compared to the other VID system smoke algorithms in that the smoldering sources were generally easier to detect due to more visible smoke than the flaming fires. The results may indicate that the VSD-8 system relies more on the movement or velocity of the smoke than the obscuration of the image. This is consistent with previous test results and nuisance source detection onboard the ex-USS *Shadwell* [5].

Table 45 — Test Set 4b Data from the Reproduced Test Set 4 Including the VSD-8 System at 14 Fc

Test	Source	Location	Camera 1 Optimized	Camera 2 Light Contrast	Camera 3 Dark Contrast	Camera 4 Out of Focus	Camera 5 Optimized (new)	Camera 6 Dark Contrast (new)
SFA Smoke Algorithm								
272	Flaming Boxes	1	02:36	03:58	02:45	02:33	01:53	02:08
273	Flaming Boxes	1	01:39	03:24	01:41	01:50	01:43	01:52
269	Flaming Boxes	2	02:03	DNA	02:10	02:07	02:07	02:17
274	Flaming Boxes	2	04:55	06:02	04:20	04:14	03:44	05:33
271	Smoldering Laundry	2	08:38	DNA	07:30	08:55	06:05	08:55
275	Smoldering Laundry	2	DNA	DNA	DNA	13:21	11:52	13:27
SFA Fire Algorithm								
272	Flaming Boxes	1	DNA	DNA	02:28	DNA	01:30	01:33
273	Flaming Boxes	1	DNA	DNA	DNA	DNA	DNA	01:07
269	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	05:49
274	Flaming Boxes	2	DNA	DNA	DNA	DNA	DNA	DNA
271	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA
275	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA
SigniFire Smoke Algorithm								
272	Flaming Boxes	1	01:53	01:41	02:00	01:45	DNA	02:09
273	Flaming Boxes	1	01:41	01:37	01:47	01:39	01:38	01:23
269	Flaming Boxes	2	DNA	DNA	DNA	02:59	01:44	01:37
274	Flaming Boxes	2	DNA	02:06	02:05	02:04	02:02	02:03
271	Smoldering Laundry	2	04:53	04:00	04:40	04:14	04:05	04:16
275	Smoldering Laundry	2	09:32	23:11	09:09	08:55	DNA	07:24
SigniFire Fire Algorithm								
272	Flaming Boxes	1	DNA	DNA	DNA	DNA	00:26	01:01
273	Flaming Boxes	1	DNA	DNA	DNA	DNA	00:32	00:42
269	Flaming Boxes	2	DNA	DNA	04:08	05:29	03:16	03:20
274	Flaming Boxes	2	DNA	DNA	03:41	03:39	03:32	03:31
271	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	16:29
275	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA
SigniFire Offsite Algorithm								
272	Flaming Boxes	1	02:19	01:36	02:01	02:07	01:38	01:23
273	Flaming Boxes	1	01:28	01:31	01:33	02:11	02:11	01:33
269	Flaming Boxes	2	05:10	03:51	DNA	02:51	04:52	02:41
274	Flaming Boxes	2	04:09	04:07	04:04	04:06	04:03	04:02
271	Smoldering Laundry	2	24:31	DNA	DNA	DNA	DNA	DNA
275	Smoldering Laundry	2	DNA	DNA	DNA	DNA	DNA	DNA
VSD-8 Smoke Algorithm								
272	Flaming Boxes	1	01:51	01:30	01:31	01:26	01:34	NA
273	Flaming Boxes	1	01:19	DNA	01:25	01:18	01:16	NA
269	Flaming Boxes	2	01:58	01:38	02:09	03:54	DNA	NA
274	Flaming Boxes	2	04:01	DNA	DNA	04:05	DNA	NA
271	Smoldering Laundry	2	07:26	DNA	06:20	DNA	16:35	NA
275	Smoldering Laundry	2	DNA	DNA	DNA	11:15	DNA	NA

5.6 Test Set 5 Results

Test Set 5 consisted of distributing the six cameras around the compartment with all cameras set to optimum image conditions at 14 Fc. The model SSC-DC14 cameras were located at Location 1 through 4 while the model SSC-DC393 cameras were located at Locations 5 and 6 (see Figure 12). By having different camera locations and the variation in bulkhead color, the tests were designed to determine the effect of fire sources, source location and background color on the video smoke and fire activation times. In addition, these results were used to find the optimum number of cameras and to evaluate coverage. The largest number of test locations (1, 2, 4, 5, and 6) and range of fire sources were tested in this test set. The complete set of results for all tests conducted are presented in the Master Table on the attached CD. This section presents results as they pertain to the different objectives of this test set.

The following subsections discuss the results for the following topics:

1. Impact of background color on VID performance
2. Optimum camera number and placement
3. Spot-type detector performance compared to VID system performance

5.6.1 Impact of background color on VID performance

Tests were conducted to assess the impact of background color on the performance of the VID systems. As seen in Figure 23, camera Locations 1 and 4 were located in opposite corners across the space and positioned to view the opposing corner. Figure 24 and Figure 25 show the images viewed by both cameras in Location 1 and Location 4, respectively. The compartment obstructions were symmetrically configured to produce similar images. The primary variable was background color, with one set of adjacent bulkheads painted white (the background to the view of Camera 4), and one set of bulkheads painted gray (the background to the view of Camera 1). Tables 46 through Table 50 list the results of Camera Location 1 and camera Location 4 for sources positioned directly underneath the camera (fires near field) or across the compartment obscured by cabinets (fires far field). The results in Table 46 through Table 50 are laid out in such a way that the results are paired according to fire location. For example, camera Location 1 and fire Location 4 were paired with Camera Location 4 and Fire Location 5 so both cameras are viewing a near field fire source with different colored bulkheads in the background.

Caution must be taken when comparing results in Table 46 through Table 50 not to make direct comparisons between tests with the same source on the same line for the gray and white background conditions. These tests are repeat tests (i.e., not the same test) and the order can be changed so that row-by-row comparisons can vary. Instead, all of the tests for a given source should be compared for both the gray and white background conditions. For example, in Table 46 for the far field test results, only the flaming trash can and the smoldering laundry fires yielded quicker alarm times with the white background for all test comparisons (i.e., the longest alarm time for the white background camera was lower than the shortest alarm time for the gray background cases). If a DNA (Did Not Alarm) was recorded, the time of alarm is considered greater than any given value in the Table.

Table 46 lists the SigniFire smoke algorithm alarms for various sources against differing bulkhead colors. For the near field cases, the SigniFire smoke algorithm alarmed faster for the white background in 2 out of 4 data sets (i.e., four source types) with the two remaining data sets being indeterminate (neither favoring the white nor the gray). The faster responses were for the smoldering laundry and flaming trashcan fires. With the white background, only one out of the nine fires was not detected, compared to the gray background where Camera 1 did not detect three of these nine fires. This result is consistent with earlier findings that lighter contrast and brighter light levels in the space generally resulted in improved performance for the VID smoke algorithms. The SigniFire smoke algorithm for the far field cases showed no consistent preference for either the white or gray backgrounds; one set of tests favored the white background (smoldering cables), one data set favored the gray background (smoldering laundry), and the two remaining sets were indeterminate. Similar to the near field cases, there were three cases in which Camera 1 did not alarm. Out of the eight comparisons in Table 46 (four fuels for

both near and far field cases), four were inconclusive and three showed faster responses for the white background cases and one set favored the gray.

Table 47 lists the SigniFire fire algorithm alarm times for various sources in the near and far field against differing bulkhead colors. As can be seen in the Table, there was only one alarm from the SigniFire fire algorithm. The near field fire location was under the cameras and the cabinets located on the deck obscured the far field view. Therefore in all cases, the flaming sources were placed out of the direct line of sight of the cameras. The results highlight the importance of having multiple alarm algorithms (i.e., smoke and fire) in order to have proper coverage and detection response for a space, regardless of where the source may be. As indicated in Table 46, the smoke algorithm detected most of the fires that were not detected by the fire algorithm. Obviously, with the absence of data for the SigniFire fire algorithm, no conclusions can be made about the effect of bulkhead color on detection.

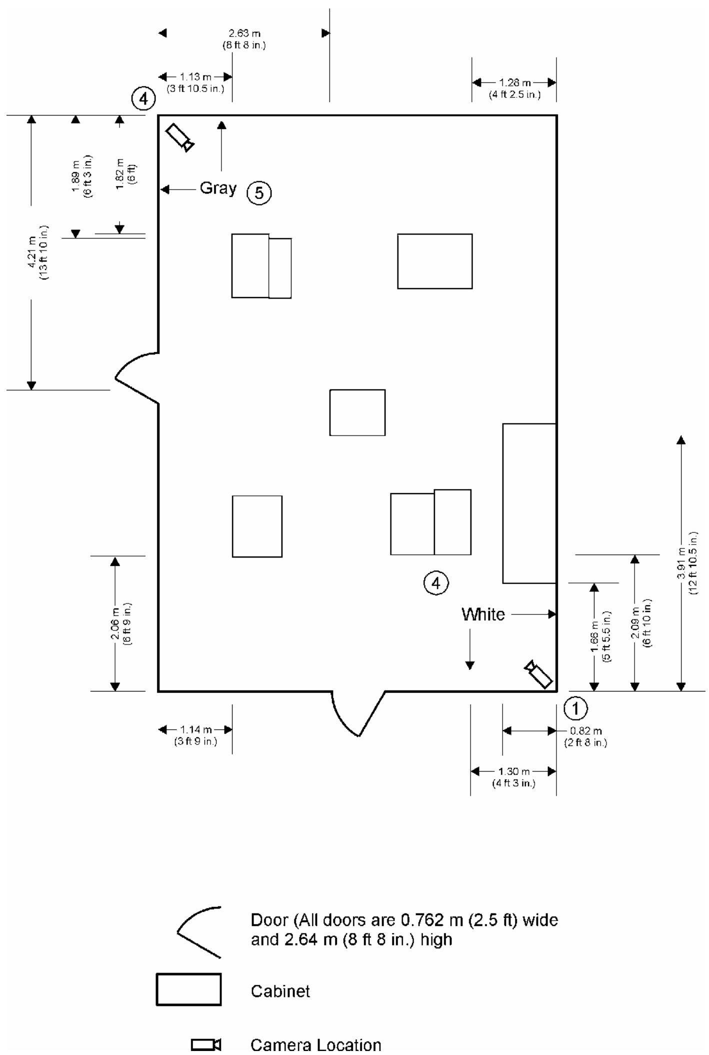

Fig. 23 — Symmetrical layout of obstructions placed in Compartment 1 relative to Camera Locations 1 and 4 and Fire Locations 4 and 5

Fig. 24 — Image from Camera Location 1 facing the gray bulkhead

Fig. 25 — Image from Camera Location 4 facing the white bulkhead

Table 46 — Comparison of White and Gray Backgrounds on the Performance of the Signifire Smoke Alarm Times (min:sec)

SigniFire Smoke Alarms for Near Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
99	Flaming Boxes	4	01:46	DNA	5	Flaming Boxes	101
100	Flaming Boxes	4	03:13	02:50	5	Flaming Boxes	104
118	Flaming Trash Can	4	05:43	03:35	5	Flaming Trash Can	116
119	Flaming Trash Can	4	DNA	01:21	5	Flaming Trash Can	117
120	Flaming Trash Can	4	07:00	02:31	5	Flaming Trash Can	121
124	Smoldering Cable	4	03:46	09:42	5	Smoldering Cable	122
125	Smoldering Cable	4	04:48	03:18	5	Smoldering Cable	126
109	Smoldering Laundry	4	DNA	03:56	5	Smoldering Laundry	111
110	Smoldering Laundry	4	DNA	04:00	5	Smoldering Laundry	112
SigniFire Smoke Alarms for Far Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
101	Flaming Boxes	5	DNA	02:02	4	Flaming Boxes	99
104	Flaming Boxes	5	01:14	03:02	4	Flaming Boxes	100
116	Flaming Trash Can	5	15:47	03:31	4	Flaming Trash Can	118
117	Flaming Trash Can	5	02:04	05:13	4	Flaming Trash Can	119
121	Flaming Trash Can	5	DNA	06:24	4	Flaming Trash Can	120
122	Smoldering Cable	5	DNA	09:47	4	Smoldering Cable	124
126	Smoldering Cable	5	09:48	09:34	4	Smoldering Cable	125
111	Smoldering Laundry	5	05:32	13:12	4	Smoldering Laundry	109
112	Smoldering Laundry	5	05:47	11:48	4	Smoldering Laundry	110

Table 47 — Comparison of White and Gray Backgrounds on the Performance of the Signifire Smoke Alarm Times (min:sec)

SigniFire Fire Alarms for Near Field Fires					
Gray			**White**		
Test	Source	Camera 1	Camera 4	Source	Test
99	Flaming Boxes	04:25	DNA	Flaming Boxes	101
100	Flaming Boxes	DNA	DNA	Flaming Boxes	104
118	Flaming Trash Can	DNA	DNA	Flaming Trash Can	116
119	Flaming Trash Can	DNA	DNA	Flaming Trash Can	117
120	Flaming Trash Can	DNA	DNA	Flaming Trash Can	121
124	Smoldering Cable	DNA	DNA	Smoldering Cable	122
125	Smoldering Cable	DNA	DNA	Smoldering Cable	126
109	Smoldering Laundry	DNA	DNA	Smoldering Laundry	111
110	Smoldering Laundry	DNA	DNA	Smoldering Laundry	112
SigniFire Fire Alarms for Far Field Fires					
Gray			**White**		
Test	Source	Camera 1	Camera 4	Source	Test
101	Flaming Boxes	DNA	DNA	Flaming Boxes	99
104	Flaming Boxes	DNA	DNA	Flaming Boxes	100
116	Flaming Trash Can	DNA	DNA	Flaming Trash Can	118
117	Flaming Trash Can	DNA	DNA	Flaming Trash Can	119
121	Flaming Trash Can	DNA	DNA	Flaming Trash Can	120
122	Smoldering Cable	DNA	DNA	Smoldering Cable	124
126	Smoldering Cable	DNA	DNA	Smoldering Cable	125
111	Smoldering Laundry	DNA	DNA	Smoldering Laundry	109

112	Smoldering Laundry	DNA	DNA	Smoldering Laundry	110

Table 48 — Comparison of White and Gray Backgrounds on the Performance of the Signifire System Offsite Alarm Times (min:sec)

SigniFire Offsite Alarms for Near Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
99	Flaming Boxes	4	04:29	03:07	5	Flaming Boxes	101
100	Flaming Boxes	4	02:50	02:16	5	Flaming Boxes	104
118	Flaming Trash Can	4	DNA	DNA	5	Flaming Trash Can	116
119	Flaming Trash Can	4	DNA	DNA	5	Flaming Trash Can	117
120	Flaming Trash Can	4	DNA	DNA	5	Flaming Trash Can	121
124	Smoldering Cable	4	DNA	DNA	5	Smoldering Cable	122
125	Smoldering Cable	4	DNA	DNA	5	Smoldering Cable	126
109	Smoldering Laundry	4	DNA	DNA	5	Smoldering Laundry	111
110	Smoldering Laundry	4	DNA	DNA	5	Smoldering Laundry	112
SigniFire Offsite Alarms for Far Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
101	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	99
104	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	100
116	Flaming Trash Can	5	DNA	DNA	4	Flaming Trash Can	118
117	Flaming Trash Can	5	DNA	DNA	4	Flaming Trash Can	119
121	Flaming Trash Can	5	DNA	DNA	4	Flaming Trash Can	120
122	Smoldering Cable	5	DNA	DNA	4	Smoldering Cable	124
126	Smoldering Cable	5	DNA	DNA	4	Smoldering Cable	125
111	Smoldering Laundry	5	DNA	DNA	4	Smoldering Laundry	109
112	Smoldering Laundry	5	DNA	DNA	4	Smoldering Laundry	110

Table 49 — Comparison of White and Gray Backgrounds on the Performance of the SFA Smoke Alarm Times (min:sec)

SFA Smoke Alarms for Near Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
99	Flaming Boxes	4	01:54	02:15	5	Flaming Boxes	101
100	Flaming Boxes	4	01:56	01:36	5	Flaming Boxes	104
118	Flaming Trash Can	4	03:06	02:40	5	Flaming Trash Can	116
119	Flaming Trash Can	4	04:03	01:10	5	Flaming Trash Can	117
120	Flaming Trash Can	4	06:49	02:30	5	Flaming Trash Can	121
124	Smoldering Cable	4	03:08	05:26	5	Smoldering Cable	122
125	Smoldering Cable	4	04:37	02:40	5	Smoldering Cable	126
109	Smoldering Laundry	4	03:52	02:59	5	Smoldering Laundry	111
110	Smoldering Laundry	4	04:29	03:09	5	Smoldering Laundry	112
SFA Smoke Alarms for Far Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
101	Flaming Boxes	5	03:07	02:30	4	Flaming Boxes	99
104	Flaming Boxes	5	01:19	02:40	4	Flaming Boxes	100
116	Flaming Trash Can	5	05:49	03:45	4	Flaming Trash Can	118
117	Flaming Trash Can	5	02:44	05:40	4	Flaming Trash Can	119
121	Flaming Trash Can	5	04:12	DNA	4	Flaming Trash Can	120
122	Smoldering Cable	5	DNA	10:14	4	Smoldering Cable	124
126	Smoldering Cable	5	DNA	11:12	4	Smoldering Cable	125
111	Smoldering Laundry	5	12:09	09:20	4	Smoldering Laundry	109
112	Smoldering Laundry	5	16:08	09:14	4	Smoldering Laundry	110

Table 50 — Comparison of White and Gray Backgrounds on the Performance of the SFA Fire Alarm Times (min:sec)

SFA Fire Alarms for Near Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
99	Flaming Boxes	4	03:37	DNA	5	Flaming Boxes	101
100	Flaming Boxes	4	DNA	DNA	5	Flaming Boxes	104
118	Flaming Trash Can	4	DNA	DNA	5	Flaming Trash Can	116
119	Flaming Trash Can	4	DNA	DNA	5	Flaming Trash Can	117
120	Flaming Trash Can	4	DNA	DNA	5	Flaming Trash Can	121
124	Smoldering Cable	4	DNA	DNA	5	Smoldering Cable	122
125	Smoldering Cable	4	DNA	DNA	5	Smoldering Cable	126
109	Smoldering Laundry	4	DNA	DNA	5	Smoldering Laundry	111
110	Smoldering Laundry	4	DNA	DNA	5	Smoldering Laundry	112
SFA Fire Alarms for Far Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
101	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	99
104	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	100
116	Flaming Trash Can	5	DNA	DNA	4	Flaming Trash Can	118
117	Flaming Trash Can	5	DNA	DNA	4	Flaming Trash Can	119
121	Flaming Trash Can	5	DNA	DNA	4	Flaming Trash Can	120
122	Smoldering Cable	5	DNA	DNA	4	Smoldering Cable	124
126	Smoldering Cable	5	DNA	DNA	4	Smoldering Cable	125
111	Smoldering Laundry	5	DNA	DNA	4	Smoldering Laundry	109
112	Smoldering Laundry	5	DNA	DNA	4	Smoldering Laundry	110

Table 48 presents the SigniFire offsite algorithm alarm times for various fires in the near and far field with differing background colors. The SigniFire offsite algorithm was not able to detect any flaming fire located in the far field. The offsite algorithm was only able to detect the flaming boxes in the near field cases. For these box fires, neither the white nor gray background produced consistently faster alarms. Therefore, with the limited data available for the SigniFire offsite algorithm, the effect of background color on offsite detection cannot be ascertained. The results do indicate that the offsite alarm algorithm may need relatively bright or sizable reflection areas in the video for effective detection.

Table 49 presents the SFA smoke algorithm alarm times for various fires in the near and far field with differing background colors. For the near field fires, the SFA smoke algorithm alarmed faster (~ 1 to 4 minutes) with the white background in 2 out of 4 test sets (i.e., the trash can and laundry fires) with the other two test sets being indeterminate. These results were the same as those of the SigniFire smoke algorithm. In the far field cases, two test sets (i.e., the smoldering cable and smoldering laundry tests) resulted in faster alarm times for the white background, while the other two sets were indeterminate. For the smoldering laundry, the white background resulted in alarms that were about 3 to 7 minutes faster, and for the smoldering cable fires, the white background had alarm times of 10 and 11 minutes and no alarms occurred for the gray background. Out of all eight comparisons in Table 49 (i.e., four fires for both near and far field cases), four were inconclusive and four showed faster responses for the white background. Therefore, similar to the SigniFire smoke algorithm, the indication of better

performance with the white background is consistent with earlier findings that lighter contrast and brighter light levels in the space generally resulted in faster response by the VID smoke algorithm.

The results for the SFA fire algorithm with white and gray backgrounds are presented in Table 50. Similar to the SigniFire results, only one test caused an alarm. With the lack of responses for the SFA fire algorithm, no conclusions can be made about the effect of bulkhead color on the SFA flame algorithm.

The background tests presented in Tables 46 through 50 were run with the older model SSC-DC14 Sony cameras. Due to the lack of alarms, the SFA and SigniFire fire algorithm results and the SigniFire offsite results were not useful in evaluating the effect of background conditions on these alarm algorithms. The smoke algorithms, however, were shown to produce faster alarms with the white background for 7 out of 16 data sets and the gray bulkhead produced faster results in only 1 out of the 16 data sets, with 8 data sets remaining inconclusive. Limited VSD-8 results were recorded and these were inconclusive. A second set of background color tests (Tests 229 to 238 and Tests 245 to 253) were conducted after replacing the SSC-DC14 cameras used in Location 1 and Location 4 with the newer model SSC-DC393 cameras. The results for these tests are shown below in Tables 51 through 56.

Table 51 lists the SigniFire smoke algorithm alarm times using the newer model cameras for various sources in the near and far field with differing background colors. The near field SigniFire smoke alarm results did not clearly indicate better performance for either background color; all data set comparisons were indeterminate. For the far field cases, the smoke algorithm yielded faster alarms with the gray background (flaming boxes (plastic)) and the other three sets were indeterminate. Overall, out of the eight comparisons in Table 51 (four fuels for near and far field cases), seven were inconclusive and one showed faster responses for the gray bulkhead.

Table 52 lists the SigniFire flame algorithm alarm times using the newer model cameras for various sources in the near and far field with differing background colors. The SigniFire fire alarm results do not show any consistent difference in performance for either the white or the gray background. However, comparing flaming box fire results to those in Table 47 for the older model cameras shows that the new model cameras were able to more consistently detect the fires in the near field.

Table 53 lists the SigniFire offsite flame algorithm alarm times using the newer model cameras for various sources in the near and far field with differing background colors. Similar to the previous results for the older model cameras, the offsite algorithm detected only part of the near field fires and none of the far field fire cases. For the near field cases, the SigniFire offsite algorithm alarmed faster with the white background for one data set (the flaming boxes with plastic), but the rest of the data sets were indeterminate. Given the limited data, the general conclusion is that the performance of the offsite algorithm was not impacted by the background color. The alarm times for the near field flaming box fires with the newer model cameras were about one to three minutes faster than the alarm times with the older model cameras. The cameras did not impact the detection performance for any other conditions.

Table 51 — Comparison of White and Gray Backgrounds on the Performance of the Signifire Smoke Algorithm Using the Newer Model Cameras, Alarm Times Listed in (min:sec)

SigniFire Smoke Alarms for Near Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
231	Flaming Boxes	4	02:29	03:18	5	Flaming Boxes	229
232	Flaming Boxes	4	06:12	02:52	5	Flaming Boxes	230
238	Flaming Boxes	4	01:37	DNA	5	Flaming Boxes	237
234	Flaming Boxes (plastic)	4	03:11	03:15	5	Flaming Boxes (plastic)	233
236	Flaming Boxes (plastic)	4	02:11	02:58	5	Flaming Boxes (plastic)	235
246	Trash Fire (smoldering)	4	00:53	02:39	5	Trash Fire (smoldering)	250
247	Trash Fire (smoldering)	4	01:16	01:14	5	Trash Fire (smoldering)	251
248	Trash Fire (smoldering)	4	01:16	DNA	5	Trash Fire (smoldering)	252
249	Trash Fire (smoldering)	4	00:56	02:07	5	Trash Fire (smoldering)	253
SigniFire Smokes Alarm for Far Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
229	Flaming Boxes	5	DNA	04:59	4	Flaming Boxes	231
230	Flaming Boxes	5	03:39	03:11	4	Flaming Boxes	232
237	Flaming Boxes	5	02:57	DNA	4	Flaming Boxes	238
233	Flaming Boxes (plastic)	5	04:33	08:34	4	Flaming Boxes (plastic)	234
235	Flaming Boxes (plastic)	5	04:33	06:01	4	Flaming Boxes (plastic)	236
250	Trash Fire (smoldering)	5	06:09	02:04	4	Trash Fire (smoldering)	246
251	Trash Fire (smoldering)	5	03:19	04:03	4	Trash Fire (smoldering)	247
252	Trash Fire (smoldering)	5	01:45	11:33	4	Trash Fire (smoldering)	248
253	Trash Fire (smoldering)	5	03:33	04:57	4	Trash Fire (smoldering)	249

Table 52 — Comparison on White ad Gray Backgrounds on the Performance of the Signifire Fire Algorithm Using the Newer Model Cameras, Alarm Times Listed in (min:sec)

SigniFire Fire Alarms for Near Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
231	Flaming Boxes	4	02:32	04:02	5	Flaming Boxes	229
232	Flaming Boxes	4	DNA	03:21	5	Flaming Boxes	230
238	Flaming Boxes	4	00:34	04:59	5	Flaming Boxes	237
234	Flaming Boxes (plastic)	4	02:30	03:06	5	Flaming Boxes (plastic)	233
236	Flaming Boxes (plastic)	4	01:02	01:57	5	Flaming Boxes (plastic)	235
246	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	250
247	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	251
248	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	252
249	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	253
SigniFire Fire Alarms for Far Field Fires							
Gray				**White**			
Test	Source	Location	Camera 4	Camera 1	Location	Source	Test
231	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	229
232	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	230
238	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	237
234	Flaming Boxes (plastic)	5	DNA	DNA	4	Flaming Boxes (plastic)	233
236	Flaming Boxes (plastic)	5	DNA	DNA	4	Flaming Boxes (plastic)	235
246	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	250
247	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	251
248	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	252
249	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	253

Table 53 — Comparison of White and Gray Backgrounds on the Performance of the Signifire Offsite Algorithm Using the Newer Model Cameras, Alarm Times Listed in (min:sec)

SigniFire Offsite Alarms for Near Field Fires							
Gray					**White**		
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
231	Flaming Boxes	4	01:53	01:40	5	Flaming Boxes	229
232	Flaming Boxes	4	01:19	01:28	5	Flaming Boxes	230
238	Flaming Boxes	4	01:10	01:22	5	Flaming Boxes	237
234	Flaming Boxes (plastic)	4	01:35	01:24	5	Flaming Boxes (plastic)	233
236	Flaming Boxes (plastic)	4	01:32	01:26	5	Flaming Boxes (plastic)	235
246	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	250
247	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	251
248	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	252
249	Trash Fire (smoldering)	4	11:12	DNA	5	Trash Fire (smoldering)	253
SigniFire Offsite Alarms for Far Field Fires							
Gray					**White**		
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
229	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	231
230	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	232
237	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	238
233	Flaming Boxes (plastic)	5	DNA	DNA	4	Flaming Boxes (plastic)	234
235	Flaming Boxes (plastic)	5	DNA	DNA	4	Flaming Boxes (plastic)	236
250	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	246
251	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	247
252	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	248
253	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	249

Table 54 lists the SFA smoke algorithm alarm times using the newer model cameras for various sources in the near and far field with differing background colors. The SFA smoke algorithm responded faster in both the near and far field cases with the gray background in one out of three test sets (flaming boxes with plastic). The remaining test sets in both the near and far field were indeterminate. Overall, these results indicated that the background color had little systematic effect on the performance of the smoke algorithm with the newer cameras. Comparing the alarm times to the flaming boxes with those obtained for the older model cameras (see Table 49) shows that there were fewer alarms obtained (5 of 12) for the newer camera models than the older model (12 of 12 fires detected).

Table 55 lists the SFA flame algorithm alarm times using the newer model cameras for various sources in the near and far field with differing background colors. The SFA flame algorithm alarmed faster in the near field fires in one of three test sets for the gray background (the flaming boxes with plastic). The remaining data sets showed no difference in performance for the white and gray backgrounds. Similar to the SigniFire flame algorithm, the SFA flame algorithm demonstrated better performance for the flaming box fires with new model cameras compared to the older model cameras. Table 55 shows that the flame algorithm with the new model camera alarmed for all six of the near field flaming boxes, while only detecting one of four of the fires with the older model cameras (Table 50).

Table 54 — Comparison of White and Gray Backgrounds on the Performance of the SFA Smoke Algorithm Using the Newer Model Cameras, Alarm Times Listed in (min:sec)

SFA Smoke Alarms for Near Field Fires							
Gray				White			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
231	Flaming Boxes	4	04:54	DNA	5	Flaming Boxes	229
232	Flaming Boxes	4	09:01	DNA	5	Flaming Boxes	230
238	Flaming Boxes	4	01:39	02:30	5	Flaming Boxes	237
234	Flaming Boxes (plastic)	4	02:24	03:34	5	Flaming Boxes (plastic)	233
236	Flaming Boxes (plastic)	4	03:30	03:38	5	Flaming Boxes (plastic)	235
246	Trash Fire (smoldering)	4	00:59	02:41	5	Trash Fire (smoldering)	250
247	Trash Fire (smoldering)	4	01:13	01:03	5	Trash Fire (smoldering)	251
248	Trash Fire (smoldering)	4	01:27	00:16	5	Trash Fire (smoldering)	252
249	Trash Fire (smoldering)	4	01:13	02:22	5	Trash Fire (smoldering)	253
SFA Smoke Alarms for Far Field Fires							
Gray				White			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
229	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	231
230	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	232
237	Flaming Boxes	5	DNA	06:41	4	Flaming Boxes	238
233	Flaming Boxes (plastic)	5	04:18	05:30	4	Flaming Boxes (plastic)	234
235	Flaming Boxes (plastic)	5	04:08	05:03	4	Flaming Boxes (plastic)	236
250	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	246
251	Trash Fire (smoldering)	5	06:14	05:15	4	Trash Fire (smoldering)	247
252	Trash Fire (smoldering)	5	03:05	05:29	4	Trash Fire (smoldering)	248
253	Trash Fire (smoldering)	5	17:42	06:06	4	Trash Fire (smoldering)	249

Table 55 — Comparison of White and Gray Backgrounds on the Performance of the SFA Fire Algorithm Using the Newer Model Cameras, Alarm Times Listed in (min:sec)

SFA Fire Alarms for Near Field Fires							
Gray				White			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
231	Flaming Boxes	4	04:01	03:26	5	Flaming Boxes	229
232	Flaming Boxes	4	05:22	02:50	5	Flaming Boxes	230
238	Flaming Boxes	4	01:05	01:55	5	Flaming Boxes	237
234	Flaming Boxes (plastic)	4	01:27	03:15	5	Flaming Boxes (plastic)	233
236	Flaming Boxes (plastic)	4	01:27	01:35	5	Flaming Boxes (plastic)	235
246	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	250
247	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	251
248	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	252
249	Trash Fire (smoldering)	4	DNA	17:36	5	Trash Fire (smoldering)	253
SFA Fire Alarms for Far Field Fires							
Gray				White			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
229	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	231
230	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	232
237	Flaming Boxes	5	DNA	DNA	4	Flaming Boxes	238
233	Flaming Boxes (plastic)	5	DNA	DNA	4	Flaming Boxes (plastic)	234
235	Flaming Boxes (plastic)	5	DNA	DNA	4	Flaming Boxes (plastic)	236
250	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	246
251	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	247
252	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	248
253	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	249

Table 56 lists the VSD-8 smoke algorithm alarm times using the newer model cameras for various sources in the near and far field with differing background colors. For the tests conducted, the VSD-8 system alarmed faster with the white background for one out of the three near field fire test sets and for two out of three far field test sets with the gray background. The remaining test sets were indeterminate, neither the white or gray background always providing faster results.

Table 56 — Comparison of White and Gray Backgrounds on the Performance of the VSD-8 Smoke Algorithm Using the Newer Model Cameras, Alarm Times Listed in (min:sec)

VSD-8 Alarms for Near Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
231	Flaming Boxes	4	02:23	03:33	5	Flaming Boxes	229
232	Flaming Boxes	4	01:51	02:46	5	Flaming Boxes	230
238	Flaming Boxes	4	DNA	02:26	5	Flaming Boxes	237
234	Flaming Boxes (plastic)	4	DNA	02:54	5	Flaming Boxes (plastic)	233
236	Flaming Boxes (plastic)	4	03:24	01:25	5	Flaming Boxes (plastic)	235
246	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	250
247	Trash Fire (smoldering)	4	04:26	01:30	5	Trash Fire (smoldering)	251
248	Trash Fire (smoldering)	4	05:23	DNA	5	Trash Fire (smoldering)	252
249	Trash Fire (smoldering)	4	DNA	DNA	5	Trash Fire (smoldering)	253
VSD-8 Alarms for Far Field Fires							
Gray				**White**			
Test	Source	Location	Camera 1	Camera 4	Location	Source	Test
229	Flaming Boxes	5	03:46	DNA	4	Flaming Boxes	231
230	Flaming Boxes	5	02:45	DNA	4	Flaming Boxes	232
237	Flaming Boxes	5	02:31	07:26	4	Flaming Boxes	238
233	Flaming Boxes (plastic)	5	03:12	04:00	4	Flaming Boxes (plastic)	234
235	Flaming Boxes (plastic)	5	01:25	03:57	4	Flaming Boxes (plastic)	236
250	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	246
251	Trash Fire (smoldering)	5	01:20	04:25	4	Trash Fire (smoldering)	247
252	Trash Fire (smoldering)	5	03:45	05:18	4	Trash Fire (smoldering)	248
253	Trash Fire (smoldering)	5	DNA	DNA	4	Trash Fire (smoldering)	249

In summary for the new model cameras, the fire alarms generated from the flame algorithms for both the SFA and SigniFire systems, including the SigniFire offsite alarm, were inconclusive in indicating an effect on detection performance due to differences in the background color. The smoke algorithms from all three systems demonstrated a slight improvement with the gray background, 6 out of 24 test sets responding faster with the remaining 18 test sets inconclusive. The results collected indicate that the effect of potential shipboard background colors on the VID systems fire detection performance is insignificant. Slight trends are indicated favoring the white bulkheads with the older model cameras and gray bulkheads with the newer model. However, the type of fire source and location play a much greater role in detection capability and activation times. The average deviation in alarm time for the sources that favored one background over another was less than the average standard deviation of the sources themselves.

5.6.2 Evaluation of Camera Spacing

The test data, with the six cameras optimized and distributed though out Compartment 1, was used to calculate the minimum number of cameras needed to minimize the cost while maintaining high fire detection performance. The minimum camera coverage was determined by comparing the number of alarms and time of alarm activations to the current state of the art smoke detectors.

Table 57 lists the average percentage of fires detected in the compartment for the various VID systems based on the number of cameras considered as part of the compartment system. The data in Table 57 were calculated using Tests 161 to 184 (excluding 181), conducted with varying fire sources at Location 6. Location 6 was chosen so each camera was positioned geometrically unique to the source and no near field camera existed. The values represent the average level of success that any group of X number of cameras within the space had at detecting all of the fires at Location 6. For example, a value of 100% for a four camera SFA system means that every combination of four cameras in the compartment alarmed for all of the tests. Out of the six cameras in the compartment, there were 15 combinations of four cameras. The percent of correct fire classifications over the 23 tests was determined for each of the 15 combinations, and then these 15 values were averaged together and presented in Table 57. This method of calculation generalizes the results by eliminating any bias that may occur by selecting a specific set of cameras. For example, one camera set of four may have alarmed to all 23 fires (100%); however, the majority of combinations may have had about an 80 percent detection rate.

Table 57 — The Average Percentage of Fires Detected in the Compartment for the Various VID Systems Based on the Number of Cameras in a System
[Data Includes Tests 161-184 with all Fires at Source Location 6]

Number of Cameras per systems	SFA Smoke	SFA Fire	SFA[1]	SigniFire Offsite	SigniFire Smoke	SigniFire Fire	SigniFire[2]	VSD-8
1	80%	9%	80%	20%	67%	10%	70%	57%
2	94%	17%	94%	34%	84%	20%	87%	72%
3	99%	26%	99%	46%	91%	29%	93%	82%
4	100%	35%	100%	55%	95%	37%	97%	88%
5	100%	43%	100%	63%	98%	45%	99%	91%
6	100%	52%	100%	70%	100%	52%	100%	92%

[1] Includes both smoke and fire algorithms
[2] Includes all algorithms (offsite, fire and smoke)

The data in Table 57 shows the detection percentages for the number of cameras per system being very dependent on the VID system. For the SFA system using all algorithms, three camera systems in the space provided an average 99 percent detection of the fires. For the whole SigniFire system, 99 percent detection was not achieved until five cameras were used. The VSD-8 did not achieve 99 percent even with all six cameras. It is important to note that these results do not mean that a two or three camera system in the compartment is unable to provide 100 percent detection. Rather, the results indicate show the average of all two or three camera combinations, regardless of the camera placement. Some of the camera combinations, such as Cameras 2 and 5 and Cameras 3 and 4 (see Figure 12) would not likely be used in an actual two-camera design since they do not optimize the video coverage of the space. As an illustration, for the fifteen possible combinations of two-camera systems using the full SFA system, nine of the combinations alarmed for 100 percent of the fires and two of the remaining combinations alarmed for 96 percent of the fires (i.e., missed one of the 23 fires). Considering that these fires were mostly smoldering sources and were relatively small, the use of two cameras in the space would be considered adequate based on this data set.

A similar analysis was conducted with all the data from tests in Set 5 and Set 6, in order to include a wider range of fires and multiple fire locations throughout the space. The same set of six cameras were optimized and positioned around the compartment under 14 Fc illumination.

Table 58 presents the average percentage of fires detected and percentage of nuisance source alarms in the compartment for the various VID systems based on the number of cameras considered as part of the compartment system. The data of Table 58 has been plotted in Figure 26 as a Receiver Operating Characteristic (ROC) plot of the three VID systems.

The graph in Figure 26 is a ROC plot of percentage of nuisance alarms and fire sources detected for all tests in Test Sets 5 and 6. The graph in Figure 26 demonstrates the relationship between the number of alarms, both nuisance and fire, to the number of cameras in the compartment. Increasing the number of cameras increases the chance that the system will alarm during a fire, and also increases the chance that the systems will alarm during a nuisance. It can be seen in Figure 26 that the SFA and SigniFire systems reach a peak and begin to plateau between the two and three camera systems. This would indicate that one camera would not be enough to cover the 20 by 30 by 10 ft room. Upon further examination of the percentages the location of the camera in relation to the fire source and the obstructions had an impact on the activation times within Compartment 1. Corner locations appear to be the best location for covering large spans of the compartment. However, this ultimately is very dependent on the configuration and the contents of the space. The VSD-8 system data shows a different trend in Figure 26. There was no change in fire performance between one and two cameras, however nuisance alarms increased from 51 to 70 percent. With systems of more than two cameras, the detection and nuisance alarm rates relatively increase linearly.

5.6.3 Spot-Type detector Response vs. VID system response

The VID systems were compared to the current state of the art spot-type smoke detectors to determine differences in performance capabilities. Two aspects of detector performance were compared: number of fire sources detected and speed of detection. Table 59 presents the number of sources detected by each system. The spot-type detection systems have been divided by -manufacturer and detector type. Each spot-type detection system listed represents the two detectors located in Compartment 1. For example, EST Ion detects a source if either of the two EST Ion detectors located in Compartment 1 alarmed. Only one detector needed to alarm to detect the source, if both detectors alarmed it did not count twice. The VID systems were evaluated as two camera systems using camera Location 1 and camera Location 4. If one camera video image resulted in an alarm the system was considered in alarm. The numbers presented in Table 59 are the number of alarms produced from the two camera systems and spot-type detection systems subjected to the tests from Test Set 5. The SFA and SigniFire VID systems demonstrated comparable ability in detecting flaming fires to the EST and Notifier ion detection systems. The Ion detectors and SigniFire system detected 100% of the 34 flaming fire sources and the SFA system detected 33 out of the 34 tests for a 97% alarm rate. The VSD-8 system and the photoelectric detectors did not perform as well, detecting only 62% or less of the flaming fires.

Table 58 — The Average Percentage of Fires Detected and Nuisance Alarms in the Compartment for the Various VID Systems Based on the Number of Cameras in a System [Includes all Tests from Test Sets 5 and 6]

Nuisance Alarms								
Number of Cameras per system	SFA Smoke	SFA Fire	SFA[1]	SigniFire offsite	Signifire Smoke	SigniFire Fire	SigniFire[2]	VSD-8
1	21%	8%	26%	8%	13%	6%	21%	51%
2	25%	14%	33%	29%	25%	17%	36%	70%
3	28%	19%	38%	32%	28%	22%	42%	78%
4	29%	23%	42%	35%	29%	26%	45%	83%
5	30%	26%	44%	37%	30%	29%	47%	86%
6	31%	28%	45%	38%	31%	31%	48%	88%
Fire Alarms (Flaming and Smoldering)								
Number of Cameras per system	SFA Smoke	SFA Fire	SFA[1]	SigniFire offsite	Signifire Smoke	SigniFire Fire	SigniFire[2]	VSD-8
1	88%	7%	88%	18%	77%	12%	84%	63%
2	93%	13%	93%	29%	90%	22%	94%	63%
3	95%	18%	95%	36%	93%	30%	96%	70%
4	96%	22%	96%	41%	95%	36%	97%	74%
5	97%	25%	97%	43%	95%	40%	98%	77%
6	98%	28%	98%	45%	95%	43%	98%	79%

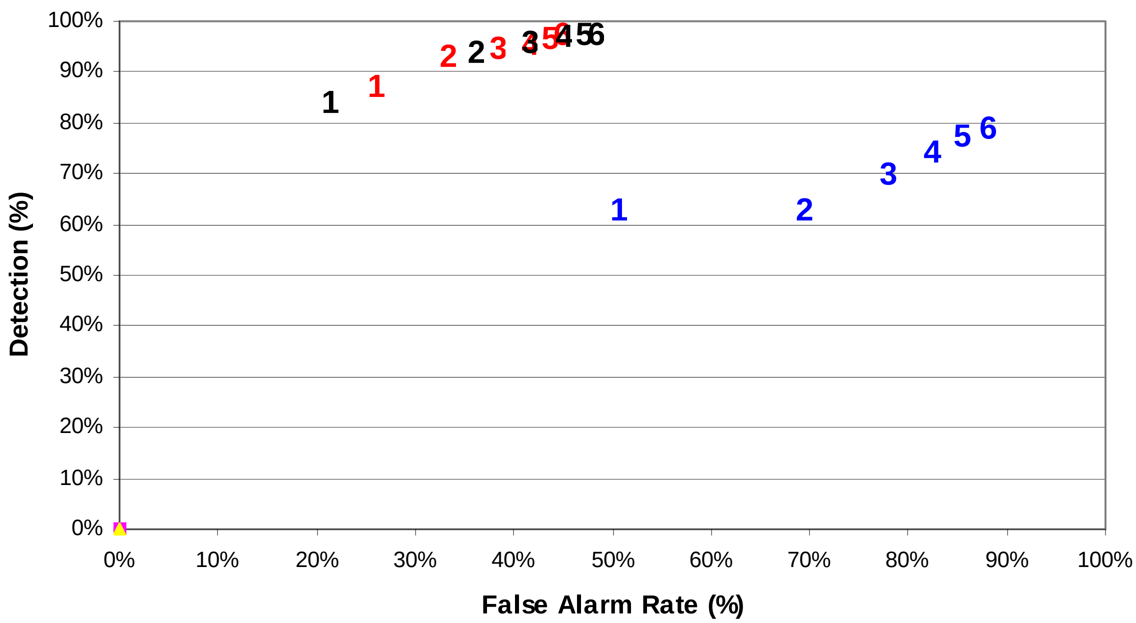

Fig. 26 — A ROC plot of % of fire sources detected versus the % of nuisance sources detected for a various number of cameras in a VID system. The numbers indicate the number of cameras in a system. The color identifies the system: black is SigniFire, red is SFA, and blue is VSD-8.

Table 59 — Ratios and Percentages of Sources Detected by Each Detection System to the Total Number of Sources Tested for Smoldering and Flaming Fires

	Number of Flaming Tests	Number of Smoldering Tests	Total Number of Tests	% Alarm Activation (Flaming)	% Alarm Activation (Smoldering)	% Alarm Activation (All Tests)
SFA	33/34	47/49	80/83	97%	96%	96%
SigniFire	34/34	45/49	79/83	100%	92%	95%
VSD-8	21/34	31/49	52/83	62%	63%	63%
EST Ion	34/34	33/49	67/83	100%	67%	81%
EST Photo	12/34	37/49	49/83	35%	76%	59%
Notifier Ion	34/34	19/49	53/83	100%	39%	64%
Notifier Photo	15/34	35/49	50/83	44%	71%	60%

The EST and Notifier photoelectric detectors were better suited for detecting the smoldering fires, detecting 76% and 71% of the smoldering sources, respectively. The VSD-8 system still performed poorly, only detecting 63% of the 49 smoldering sources. The results from the smoldering and flaming fire tests were combined to give the overall performance of the systems. The SFA and SigniFire VID systems were the only systems capable of detecting 95% of the fires or better. The next closest system was the EST Ion detection system, alarming on 81% of the fires.

The percentage values listed in Table 59 were used to calculate the difference in VID system detection capability compared to the spot-type detection systems. Table 60 contains the percentage of flaming and smoldering tests each VID system was able to detect over each of the spot-type smoke detection systems. Figure 27 is a graph of the data presented in Table 60. A positive value indicates the VID system outperformed the spot-type detectors by detecting more fire sources by the given percentage. Table 60 reveals the advantage the VID systems have over the spot-type detectors. Photoelectric and ionization detectors are generally considered better at detecting one type of combustion (i.e., smoldering or flaming, respectively). This performance difference is clearly demonstrated in Table 59. The multi-algorithm VID systems outperformed the spot-type detectors, detecting both smoldering and flaming sources. The multiple algorithms for both smoke and flame contribute to their enhanced performance. The single algorithm VSD-8 smoke detection system is the exception with marginal improvement over the photo detectors and negative values when compared to the ion detectors. The negative values indicate that the ion detectors alarmed to more fire sources than the VSD-8 system.

Table 60 — Percentage of Fire Tests that the VID Systems Detected Compared to the Various Spot-Type Smoke Detection Systems

	% better EST Ion	% better EST Photo	% better Notifier Ion	% better Notifier Photo
SFA	16%	37%	33%	36%
SigniFire	14%	36%	31%	35%
VSD	-18%	4%	-1%	2%

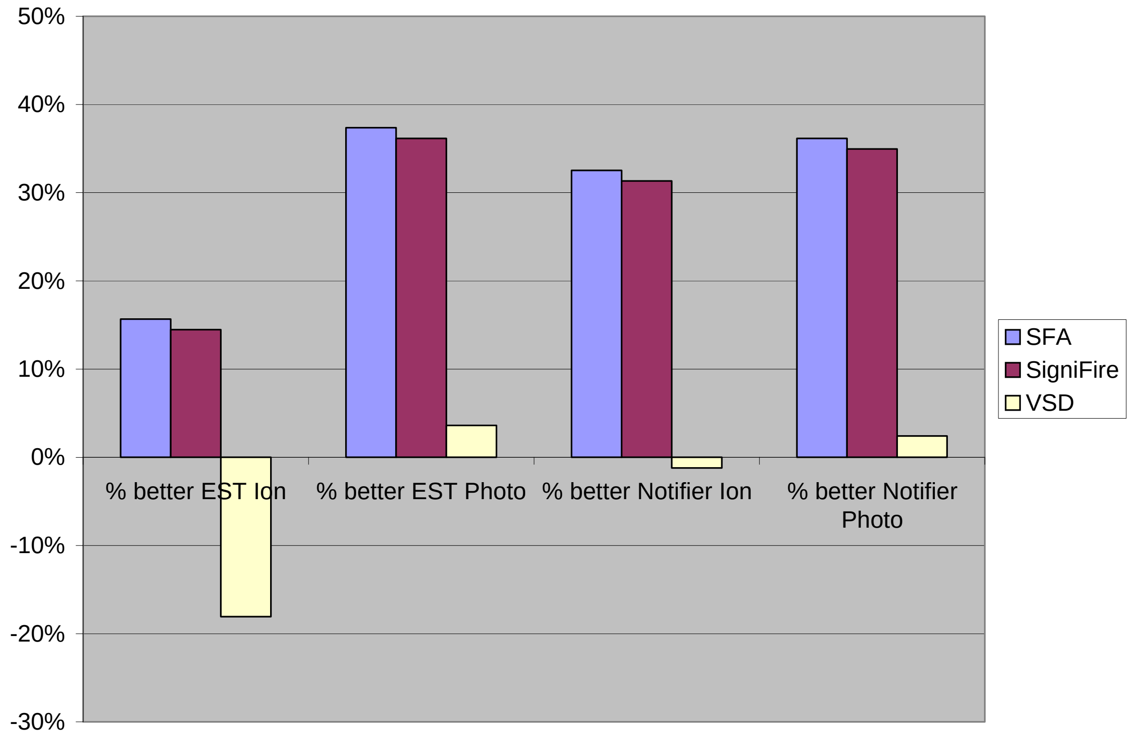

Fig. 27 — Graph of the percentage of fire tests that the VID systems detected compared to the various spot-type smoke detection systems

The VID systems and spot-type detection systems alarm times for Test Set 5 were compared for each test to identify detection performance as it pertains to speed of detection. The difference in alarm times for each VID system compared to each spot-type detection system was calculated by subtracting from the alarm time of the VID system the alarm time of each spot-type detection system. If the value was negative it indicated a smaller VID alarm time and better VID performance. If the value was positive it indicated a larger VID alarm time and inferior VID performance. If one of the systems did not alarm (DNA) a difference could not be calculated; however, the DNA was considered to be in favor of the other system. For example, if the VID system did not alarm, the value was considered to be a positive indicator of better spot-type detector performance. If both systems did not alarm the difference was listed as DNA and did not count for or against either system. The VID systems were composed of alarm times from a two camera system consisting of Camera Location 1 and Location 4 only. The number of positive values (both alarm time and positive DNA's) and the number of negative values (both alarm time and negative DNA's) were counted up for the smoldering and flaming fires. The results for the three VID systems are listed in Tables 61, 62, and 63. Tables 61 and 62 show the same general trend for both of the multi-algorithm VID systems of alarming faster than the spot-type detectors for a majority of the comparisons. The SFA VID system (Table 61) detected more fires faster, independent of fire type and type of smoke detector with the exception of flaming fires detected by the ion detection systems. During smoldering tests, the spot-type detectors alarmed quicker only twice, clearly showing that the VID systems provided faster responses to these fires.

Table 61 — Number of Tests that Produced Faster Alarm Times when Comparing the SFA and Spot-Type Detection Systems for Flaming and Smoldering Sources. If Both System did not Produce an Alarm it was Counted as a did not Alarm (DNA).

	SFA VID vs. EST Ion	SFA VID vs. EST Photo	SFA VID vs. Notifier Ion	SFA VID vs. Notifier Photo
VID (flaming)	6	33	13	32
Spot (flaming)	28	0	21	1
DNA (flaming)	0	1	0	1
VID (smoldering)	47	46	47	47
Spot (smoldering)	1	1	0	0
DNA (smoldering)	1	2	2	2

Table 62 — Number of Tests that Produced Faster Alarm Times when Comparing the Signifire and Spot-Type Detection System for Flaming and Smoldering Sources. If Both Systems did not Produce an Alarm it was Counted as a did not Alarm (DNA).

	SigniFire VID vs. EST Ion	SigniFire VID vs. EST Photo	SigniFire VID vs. Notifier Ion	SigniFire VID vs. Notifier Photo
VID (flaming)	18	34	23	31
Spot (flaming)	16	0	11	3
DNA (flaming)	0	0	0	0
VID (smoldering)	45	41	45	31
Spot (smoldering)	1	4	0	14
DNA (smoldering)	3	4	4	4

Table 63 — Number of Tests that Produced Faster Alarm Times when Comparing the VSD-8 and Spot-Type Detection Systems for Flaming and Smoldering Sources. If Both Systems did not Produce an Alarm it was Counted as a did not Alarm (DNA).

	VSD VID vs. EST Ion	VSD VID vs. EST Photo	VSD VID vs. Notifier Ion	VSD VID vs. Notifier Photo
VID (flaming)	5	16	7	16
Spot (flaming)	29	8	27	11
DNA (flaming)	0	10	0	7
VID (smoldering)	25	23	28	27
Spot (smoldering)	17	20	7	14
DNA (smoldering)	7	6	14	8

The SigniFire system alarmed faster to more flaming fires than the SFA, VSD-8, or spot-type detectors, with faster alarm times independent of source and type of smoke detector. Similar to the SFA system, the Signifire system dominated the spot-type detection systems in the number of smoldering fires for which it alarmed faster. Table 63 lists the results for the VSD-8 system. The VSD-8 system was comparable to the spot-type detection systems. During the flaming fires, however, the VSD-8 system did slightly outperform the photoelectric detectors; it under performed when compared to the ion detectors.

Tables 64, 65, and 66 present the average time in seconds that the VID systems alarmed faster than the spot-type detectors to the Test Set 5 smoldering and flaming fires and the average time the spot-type detectors alarmed faster than the VID systems to the Test Set 5 flaming and smoldering sources. Zeros indicate that alarm times did not exist for comparison; although, one system may have alarmed faster if it alarmed and the other system did not (i.e., if one system had only DNA events, an average difference between system alarm times could not be calculated though one system was faster). The VID systems generally produced average alarm times faster than the spot-type detectors by as much as 143 seconds for flaming sources and 542 seconds for smoldering sources. The spot-type detectors can be 402 seconds faster for the smoldering sources and 143 seconds faster for the flaming fires. The average difference in alarm times listed in Tables 64, 65, and 66 can be misinterpreted when the systems performance as a whole is not taken into consideration. The number of fires that are detected, the alarm times, and the number of alarms that are faster should all be taken into consideration when comparing two systems.

Table 64 — The Average Difference in Alarm Times (Sec) for all Test Set 5 Fires for SFA and Spot-Type Detectors. The number of tests included in the average are shown in parenthesis.

SFA	**Time Difference (# of tests)**			
	EST Ion	**EST Photo**	**Notifier Ion**	**Notifier Photo**
Flaming tests (SFA faster)	32 (6)	95 (12)	49 (13)	99 (14)
Flaming tests (Spot-Type faster)	113 (27)	0 (1)	117 (20)	4 (1)
Smoldering tests (SFA faster)	358 (32)	235 (36)	465 (19)	449 (35)
Smoldering tests (Spot-Type faster)	0 (0)	187 (1)	0 (0)	0 (0)

Table 65 — The Average Difference in Alarm Times (Sec) for all Test Set 5 Fires for SigniFire. The number of tests included in the average are shown in parenthesis.

SigniFire	Time Difference (# of tests)			
	EST Ion	**EST Photo**	**Notifier Ion**	**Notifier Photo**
Flaming tests (SigniFire faster)	42 (18)	94 (12)	62 (23)	104 (12)
Flaming tests (Spot-Type faster)	100 (16)	0 (0)	98 (11)	21 (3)
Smoldering tests (SigniFire faster)	335 (32)	245 (33)	434 (19)	477 (33)
Smoldering tests (Spot-Type faster)	0 (0)	125 (4)	0 (0)	130 (2)

Table 66 — The Average Difference in Alarm Times (Sec) for all Test Set 5 Fires for VSD-8 . The number of tests included in the average are shown in parenthesis.

VSD-8	Time Difference (# of tests)			
	EST Ion	**EST Photo**	**Notifier Ion**	**Notifier Photo**
Flaming tests (VSD-8 faster)	68 (5)	143 (4)	87 (7)	124 (4)
Flaming tests (Spot-Type faster)	143 (12)	119 (1)	122 (10)	77 (1)
Smoldering tests (VSD-8 faster)	378 (16)	247 (17)	542 (12)	477 (21)
Smoldering tests (Spot-Type faster)	287 (6)	194 (8)	402 (3)	130 (4)

The VID technologies clearly demonstrated the ability to alarm to more sources faster than the spot-type detection systems. The multi-algorithm SFA and SigniFire systems alarmed to a range of fire sources and source locations with alarm rates of 96% and 95%, respectively. The SFA and SigniFire systems also produced faster alarm times than the spot-type systems for the majority of the scenarios.

5.7 Test Set 6 Results

The nuisance source tests (Test Set 6) were conducted in conjunction with the fire tests of Test Set 5. Tests were conducted with distributed cameras set to optimal settings and 14 Fc light conditions in the space. These test conditions were used with the assumption that the VID systems would be most vulnerable to nuisance sources when generally optimized for fire detection, thus providing the most challenging assessment of nuisance source immunity. Tables 67 and 68 list the ratio of nuisance alarm activations to the number of possible alarms for the three video image detection systems and the four systems of smoke detectors.

The VID systems were analyzed on a per camera basis; that is, each of the six cameras in the space was treated as a separate system. Therefore, if a test was conducted four times, then the total number of possible alarms was 24 (4 tests x 6 cameras per test). Table 67 lists the number of tests conducted, the ratio of nuisance alarms to possible alarms for each source, and (shown in the bottom row) the number of sources that caused alarms to the total number of nuisance

sources tested. The SFA system (i.e., including both smoke and flame algorithms) alarmed for 10 of the 15 types of nuisance sources. The SigniFire system alarmed to 9 of the 15 nuisance sources, and the VSD-8 alarmed to all 15 of the 15 nuisance sources. The VSD-8 system performed the poorest, alarming to people moving in the compartment. Because many of the nuisance sources involve people in the compartment it is difficult to determine if the nuisance alarms are due to the source being tested or the presence of a person in the compartment.

Table 67 — Number of Nuisance Alarms Over the Possible Number of Alarms for the Various VID Systems.

Nuisance Source	Number of tests	SFA Smoke	SFA Fire	SFA[1]	SigniFire Off-site	SigniFire Smoke	SigniFire Fire	SigniFire[2]	VSD-8
Spray Aerosol (Lysol)	4	5/24	0/24	5/48	0/24	1/24	0/24	1/72	14/24
Aerosol (old spice)	2	1/12	0/12	1/24	0/12	1/12	0/12	1/36	8/12
Burnt Toast	6	21/36	1/36	22/72	0/36	17/36	0/36	17/108	17/36
Cigarette Smoke	1	0/6	0/6	0/12	0/6	0/6	0/6	0/18	6/6
Cutting Steel	2	0/12	4/12	4/24	0/12	0/12	2/12	2/36	2/12
Flash Bulb	4	0/24	0/24	0/48	0/24	0/24	0/24	0/72	17/24
Flash Light	6	0/36	0/36	0/72	0/36	0/36	1/36	1/108	16/36
Grinding Steel	2	1/12	2/12	3/12	0/12	1/12	4/12	5/36	5/12
Man in Compartment	7	0/42	0/42	0/84	0/42	0/42	0/42	0/126	22/42
Multiple people in Compartment	2	0/12	1/12	1/24	0/12	0/12	0/12	0/36	7/12
Multiple people working with flash bulb	2	1/12	1/12	2/24	0/12	0/12	0/12	0/36	7/12
Sunlight	3	1/18	0/18	1/36	0/18	0/18	0/18	0/54	5/18
Welding	2	2/12	5/12	7/24	6/12	0/12	2/12	8/36	10/12
Welding (Stick)	2	12/12	3/12	15/24	8/12	3/12	6/12	17/36	8/12
White t-shirt	6	0/36	0/36	0/72	0/36	1/36	0/36	1/108	13/36
Total Nuisance Alarms	51	44/306	17/306	61/612	14/306	24/306	15/306	53/918	157/306
Number of source alarms per number of sources		8/15	7/15	10/15	2/15	6/15	5/15	9/15	15/15

[1] Includes both smoke and fire algorithms
[2] Includes all algorithms (offsite, fire and smoke)

Table 68 — The Ratio of Nuisance Alarms to the Number of Possible Alarms for the Four Smoke Detector Systems.

Nuisance Source	Number of tests	EST Ion	EST Photo	Notifier Ion	Notifier Photo
Spray Aerosol (Lysol)	4	0/4	0/4	0/4	0/4
Aerosol (old spice)	2	0/2	0/2	0/2	0/2
Burnt Toast	6	5/6	2/6	1/6	2/6
Cigarette Smoke	1	0/1	0/1	0/1	0/1
Cutting Steel	2	2/2	0/2	2/2	0/2
Flash Bulb	4	0/4	0/4	0/4	0/4
Flash Light	6	0/6	0/6	0/6	0/6
Grinding Steel	2	2/2	0/2	0/2	0/2
Man in Compartment	7	0/7	0/7	0/7	0/7
Multiple people in Compartment	2	0/2	0/2	0/2	0/2
Multiple people working with flash bulb	2	0/2	0/2	0/2	0/2
Sunlight	3	0/3	0/3	0/3	0/3
Welding	2	0/2	0/2	0/2	0/2
Welding (Stick)	2	2/2	0/2	0/2	0/2
White t-shirt	6	0/6	0/6	0/6	0/6
Total Nuisance Alarms	51	11/51	2/51	3/51	2/51
Number of source alarms per number of sources		4/15	1/15	2/15	1/15

The toast source is a unique source in that it can transition from a nuisance source to a smoldering or flaming source. The bread was placed into the toaster and heated on the high setting for three toasting cycles. After the first toasting cycle (lasting approximately 160 seconds) the bread appeared a light brown color and was clearly edible. The bread was then placed back into the toaster for the second cycle. At approximately 225 seconds the second cycle ended. The second cycle resulted in toast that was very dark and burnt on the edges and could be considered by some as edible. The third and final cycle ended at approximately 340 seconds leaving the toast black with visible smoke pouring out of the top of the toaster. During the third cycle, the transition to a distinct plume of smoke was considered to be a point at which the source was no longer a nuisance but a possible incipient fire. The data presented in Tables 67 and 68 is not evaluated based on this criteria; when taken into account, the ion detectors were the

only detector that alarmed before the end of the second toasting stage. The VID systems and photoelectric detectors alarmed after the third stage of toasting had begun and the toaster was producing copious amounts of smoke.

Table 68 presents the nuisance source test results for the spot-type smoke detection systems. The Table presents the number of tests conducted, the ratio of nuisance alarms to possible alarms for each source, and (shown in the bottom row) the number of sources that caused alarms to the total number of nuisance sources tested. Compared to the VID systems, the spot-type smoke detectors had better performance to the particular nuisance sources tested. However, It needs to be pointed out that the nuisance sources evaluated were primarily chosen as being problematic for the VID systems. Therefore, the comparison to the smoke detectors is limited, as many of the nuisance sources were not expected to cause alarms for the smoke detectors. The EST ion alarmed to 4 of the 15 nuisance sources while the EST photo alarmed to only 1 out of the 15. The Notifier ion and photo detectors demonstrated similar results to the EST detectors with ion detectors alarming for 2 out of the 15 nuisance sources and photo detectors alarming to 1 out of the 15 nuisance sources.

In addition to the specific nuisance tests, the VID systems were monitored on a day-to-day basis as they were normally running all of the time. Based on the day-to-day operation, several observations were made that apply to all three VID systems. It was noted that objects close to the camera, within about 0.61 m (2 ft) (i.e., a person working on the camera or very close to the camera) could cause a nuisance alarm. This event must be considered when locating cameras onboard ship. It was also noted that multiple people in the test space could cause an alarm; and although testing was done to try and repeat this phenomenon limited success was achieved during the formal test scenarios in repeating these nuisance sources.

5.8 Test Set 7 Results

Tests were conducted in the passageway located adjacent to the large compartment, as shown in Figure 1. The passageway provided a space with a different aspect ratio than used in any prior tests. The change in dimensions narrowed the field of view of the cameras. The ceiling height remained at 3 m (10 ft) while the width of the compartment was narrowed to 1.2 m (4 ft) with a passageway length of 10 m (33 ft). All doorways in the passageway were closed during the tests.

Two cameras were mounted at each end of the passageway approximately 2.39 m (7 ft 10 in) above the deck. One old model SSC-DC14 Sony and one new model SSC-DC393 were placed side by side. One nightvision camera was also positioned slightly above the CCTV cameras at each end of the passageway. The SVBD test bed was re-located from Compartment 1 to the end of the passageway above the door. (2.62 m (8 ft 10 in.)). An EST ion, photoelectric and multi-sensor smoke detector along with a Notifier ion and photoelectric smoke detector were installed in the passageway. The detectors were centrally located in the passageway with a velocity probe, thermocouple and optical density meter. Obstructions were placed in the passageway in the form of ducts, running perpendicular to the passageway, and a cable tray, running down the center (see Figure 9). In addition, 7 light fixtures were placed in the passageway, providing an illumination level of 7 Fc. The lights were flush with the overhead obstructions, 0.3 m (1 ft) below the overhead.

The results for the passageway tests are presented and discussed relative to each source location that was used. The fires were generally positioned on the deck and in the overhead

cable tray at locations that were a quarter of the way down the passageway from either end (Figure 18). The cable tray source location represented a challenging scenario with a location close to the spot-type detectors and obscured from the camera views by the cable tray, lighting, and ducts. Additional fires were placed on the deck in two locations, as shown in Figure 9. The cameras are numbered corresponding to their input into the VID systems not the camera used. These were kept as input number to reduce confusion during testing and analysis.

The camera picture quality had noticeably diminished in the passageway compared to the compartment tests. This is believed to be due to the lack of color contrast in the passageway, as was provided by the electrical cabinets in Compartment 1. Camera 1 and Camera 3 were placed at passageway Location 1 facing the port side (see Figure 13). An image of the view from the cameras positioned at Location 1 can be seen in Figure 28. Camera 4 and Camera 6 were placed at passageway Location 2 facing the starboard side. An image of the view from the cameras positioned at Location 2 in the passageway can be seen in Figure 29. Source Locations 8 and 9 were considered to be in the far field of camera Location 2 while source Location 10 is considered far field to camera Location 1.

5.8.1 Source Location 10 Tests

Tables 69 to 72 present the alarm times for the VID systems and spot-type detection systems for flaming box fires and smoldering cables at Location 10 in the passageway (see Figure 18) Table 69 shows that at source Location 10 the SFA system demonstrated the ability to detect a flaming box fire with both smoke and fire algorithms in the near and far field. The smoldering cable fires proved to be harder to detect in the near field for both the smoke and fire algorithms. Due to the lack of a flame, the fire algorithm was unable to detect the smoldering cable fires regardless of location, as will be further shown below for the other VID systems. However, the total VID systems including all complimentary algorithms were able to detect almost every fire with all camera images.

Fig. 28 — Image of the view from Camera 1 mounted at passageway Location 1, facing the port side

Fig. 29 — Image of the view from Camera 4 mounted at passageway Location 2, facing the starboard side and showing a box fire at source Location 9.

Table 69 — SFA Smoke and Fire Algorithm Alarm Times for Flaming Box Fires at Passageway Location 10

Test	Source	Location	SFA Smoke Algorithms				SFA Fire Algorithms			
			Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field	Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field
201	Flaming Boxes	10	02:05	05:45	01:55	05:14	01:48	01:49	01:27	01:18
202	Flaming Boxes	10	01:39	01:43	01:11	01:34	01:23	01:29	01:08	00:58
		Average	01:52	03:44	01:33	03:24	01:36	01:39	01:18	01:08
		STDEV	00:18	02:51	00:31	02:36	00:18	00:14	00:13	00:14
223	Smoldering Cable	10	05:58	05:57	DNA	13:45	DNA	DNA	DNA	DNA
224	Smoldering Cable	10	07:16	06:13	DNA	DNA	DNA	DNA	DNA	DNA
		Average	06:37	06:05	DNA	13:45	DNA	DNA	DNA	DNA
		STDEV	00:55	00:11						

Table 70 — SigniFire Offsite, Smoke, and Fire Activation Times for a Smoldering Cable Fires and Flaming Box Fires at Location 10 in the Passageway

Test	Source	Location	SigniFire Smoke Algorithm				SigniFire Fire Algorithm				SigniFire Offsite Algorithm			
			Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field	Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field	Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field
201	Flaming Boxes	10	DNA	06:01	04:18	01:41	00:57	01:35	01:55	00:53	DNA	DNA	01:05	01:14
202	Flaming Boxes	10	DNA	02:12	01:33	01:15	00:57	01:06	01:30	00:30	DNA	DNA	00:37	00:36
		Average	DNA	04:07	02:56	01:28	00:57	01:20	01:43	00:42	DNA	DNA	00:51	00:55
		STDEV		02:42	01:57	00:18	00:00	00:21	00:18	00:16			00:20	00:27
223	Smoldering Cable	10	DNA	DNA	10:10	08:34	DNA	DNA	DNA	DNA	06:34	DNA	DNA	DNA
224	Smoldering Cable	10	DNA	DNA	02:35	02:20	DNA	DNA	DNA	DNA	07:10	DNA	DNA	DNA
		Average	DNA	DNA	06:23	05:27	DNA	DNA	DNA	DNA	06:52	DNA	DNA	DNA
		STDEV			05:22	04:24					00:25			

Table 71 — VSD-8 Smoke Alarm Times for Smoldering Cable Fires and Flaming Box Fires at Location 10 in the Passageway

			VSD-8 Alarm			
			Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field
Test	Source	Location				
201	Flaming Boxes	10	02:48	01:45	02:20	01:45
202	Flaming Boxes	10	01:27	DNA	DNA	DNA
		Average	02:08	01:45	02:20	01:45
		STDEV	00:57			
223	Smoldering Cable	10	07:30	DNA	DNA	DNA
224	Smoldering Cable	10	DNA	DNA	DNA	DNA
		Average	07:30	DNA	DNA	DNA
		STDEV				

Table 72 — Smoke Detector Activation Times for the EST and Notifier Systems for Flaming Boxes and Smoldering Cable at Location 10 in the Passageway

			Notifier Alarms		EST Alarms	
Test	Source	Location	Notifier Ion	Notifier Photo	EST Ion	EST Photo
201	Flaming Boxes	10	01:16	DNA	01:01	DNA
202	Flaming Boxes	10	01:06	01:39	00:52	01:38
		Average	01:11	01:39	00:57	01:38
		STDEV	00:07		00:06	
223	Smoldering Cable	10	DNA	DNA	DNA	15:14
224	Smoldering Cable	10	DNA	DNA	DNA	02:04
		Average	DNA	DNA	DNA	08:39
		STDEV				09:19

Table 70 presents the SigniFire smoke, fire and offsite algorithm responses for flaming box fires and smoldering cables at Location 10 in the passageway. The SigniFire smoke algorithm performed differently than the SFA system in that it did not alarm to the smoldering fires in the far field views, whereas the SFA had trouble with the near field views. As shown in the proceeding tables, none of the VID systems consistently demonstrated a strength or weakness in detection based on near or far field images in the passageway. Table 71 shows that the VSD-8 system had trouble detecting the smoldering fires in both near and far field images. Comparing the VID system results (Tables 69-71) to the spot-type detection systems (Table 72) shows that overall, the VID systems were able to detect and alarm to more smoldering fires. All of the spot-type smoke detection systems, except the EST Photo, did not alarm to the smoldering fires at Location 10. These smoldering cable fires produced smoke that rose above the cables on the deck and then stratified in the passageway at a maximum height of about 2.4 m (8 ft), such that little smoke reached the overhead. This is a common phenomenon for smoldering fires that highlights one advantage of the VID systems. The VID systems can detect smoke anywhere in an image, regardless of where the smoke actually is in the space. Whereas, the spot-type detectors require the smoke to reach the overhead and migrate laterally to enter the detectors.

Both the smoke and flame algorithms for the SFA and SigniFire systems alarmed to the flaming box fires at Location 10 for almost every camera image. The VSD-8 smoke algorithm only alarmed to about half of the video images for the flaming boxes. The spot-type source ionization smoke detection systems alarmed in comparable times to the VID systems to all of the flaming boxes, but the photo systems alarmed for only one of the two fires.

5.8.2 Source Location 9 Tests

Tables 73 to 76 present the alarm times for the VID systems and spot-type source detection systems for flaming box fires, flaming boxes filled with plastic bubble wrap, and smoldering cables at Location 9 in the passageway. At Location 9 the fire was located on the deck similar to Location 10, 3.05 m (10.0 ft) from the door instead of from the other end of the passageway 7.01 m (23 ft), making the two fire locations symmetric about the center of the passageway. Unfortunately, due to mounting constraints above the door, Cameras 1 and 3 did not have exactly the same symmetrical view of the passageway as the cameras mounted at the other end. Consequently, source Location 9 was just outside the field of view of Cameras 1 and 3, whereas Location 10 was in the field of view of Cameras 4 and 6. The results in Tables 73 and 74 for the near field cameras show that both the SFA and SigniFire fire algorithms were not able to alarm to the flaming fires that were out of the field of view.

As shown in Table 73, the SFA smoke algorithm detected all of the fires at Location 9 via all of the cameras, except for three of each of the flaming fires viewed by Camera 6. There is no particular explanation why these video images did not result in alarms. There was no systematic effect of camera type or location throughout all of the passageway tests relative to any VID system. For example, Table 75 shows that the VSD-8 system had collocated cameras that resulted in both alarms and no alarms for the same test. As indicated in previous test sets, these unexplained failures to alarm demonstrate a certain level of unpredictability in the specific algorithm responses of the VID systems. However, on a system basis (i.e., utilizing both smoke and flame algorithms), the multi-algorithm VID systems detected almost all of the fires. This is particularly true if the system consists of two cameras, one at each end of the passageway.

The performance of the systems of spot-type smoke detectors was very dependant on the type of detection technology (ionization or photoelectric). Table 76 shows the spot-type detector activation times for the flaming boxes, flaming boxes stuffed with plastic bubble wrap and smoldering cable fires at Location 9 in the passageway. The ion detection systems alarmed to all of the flaming box fires and flaming box fires stuffed with plastic bubble wrap. The photo detection systems were unable to detect a majority of the flaming box fires, but they did detect the flaming box fires stuffed with plastic bubble wrap. This tended to add more visible smoke later in the fire after the fire was able to penetrate the side of the box and reach the bubble wrap. This penetration time is reflected in the delay between the 3 to 4 minute photo response times compared to the one minute ion response times. Contrasting to the spot-type source detection systems, there were no notable differences in VID system responses to the different types of box fires. This demonstrates the broader sensitivity of the multi-algorithm VID systems to the single sensor detectors. Further evidence is provided by the poor performance of the ion systems to the smoldering cable fires contrasted by the 100 percent alarm rate by the photoelectric detection systems.

Table 73 — SFA Smoke and Fire Algorithm Alarm Times Flaming Box Fires, Flaming Boxes Filled with Plastic Bubble Wrap, and Smoldering Cable Fires at Location 9 in the Passageway

			SFA Smoke Algorithms				SFA Fire Algorithms			
Test	Source	Location	Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field	Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field
195	Flaming Boxes	9	02:32	02:41	02:01	02:25	DNA	DNA	03:23	DNA
196	Flaming Boxes	9	02:08	03:31	02:09	DNA	DNA	DNA	02:25	DNA
197	Flaming Boxes	9	02:04	02:08	02:01	DNA	DNA	DNA	04:16	DNA
191	Flaming Boxes	9	02:22	02:24	01:46	DNA	DNA	DNA	03:32	03:41
192	Flaming Boxes	9	01:56	02:04	01:45	02:11	DNA	DNA	02:14	02:44
		Average	02:12	02:34	01:56	02:18	DNA	DNA	03:10	03:12
		STDEV	00:14	00:35	00:10	00:10			00:50	00:40
190	Flaming Boxes (plastic)	9	02:12	02:10	02:25	04:15	DNA	DNA	03:30	03:44
198	Flaming Boxes (plastic)	9	01:48	03:12	01:35	DNA	DNA	DNA	02:09	DNA
199	Flaming Boxes (plastic)	9	03:28	03:13	01:54	DNA	DNA	DNA	02:32	DNA
200	Flaming Boxes (plastic)	9	03:27	04:14	02:20	DNA	DNA	DNA	01:38	DNA
		Average	02:44	03:12	02:03	04:15	DNA	DNA	02:27	03:44
		STDEV	00:51	00:51	00:23				00:47	
203	Smoldering Cable	9	07:23	05:10	17:02	08:52	DNA	DNA	DNA	DNA
204	Smoldering Cable	9	06:12	05:35	10:18	08:43	DNA	DNA	DNA	DNA
		Average	06:48	05:23	13:40	08:48	DNA	DNA	DNA	DNA
		STDEV	00:50	00:18	04:46	00:06				

Table 74 — SigniFire Offsite, Smoke, and Fire Alarm Times for Flaming Box Fires, Flaming Boxes Filled with Plastic Bubble Wrap, and Smoldering Cable Fires at Location 9 in the Passageway

			SigniFire Smoke Algorithm				SigniFire Fire Algorithm				SigniFire Offsite Algorithm			
Test	Source	Location	Camera 1 Near Field	Camera 3 Near Field	Camera 4 Far Field	Camera 6 Far Field	Camera 1 Near Field	Camera 3 Near Field	Camera 4 Far Field	Camera 6 Far Field	Camera 1 Near Field	Camera 3 Near Field	Camera 4 Far Field	Camera 6 Far Field
195	Flaming Boxes	9	DNA	04:32	02:22	02:28	DNA	DNA	02:24	02:01	03:56	03:56	04:20	03:57
196	Flaming Boxes	9	03:51	DNA	02:15	02:15	DNA	DNA	01:26	01:26	03:00	03:08	03:31	03:20
197	Flaming Boxes	9	DNA	04:01	02:16	02:09	DNA	DNA	01:30	01:30	04:18	04:20	04:48	04:40
191	Flaming Boxes	9	DNA	DNA	01:37	DNA	DNA	DNA	01:25	01:30	DNA	DNA	DNA	DNA
192	Flaming Boxes	9	DNA	DNA	01:42	DNA	DNA	DNA	01:06	01:28	DNA	DNA	DNA	DNA
		Average	03:51	04:16	02:02	02:17	DNA	DNA	01:34	01:35	03:45	03:48	04:13	03:59
		STDEV		00:22	00:21	00:10			00:29	00:15	00:40	00:37	00:39	00:40
190	Flaming Boxes (plastic)	9	06:05	04:16	03:45	04:26	DNA	DNA	02:57	03:08	DNA	DNA	DNA	DNA
198	Flaming Boxes (plastic)	9	DNA	DNA	03:09	03:44	DNA	DNA	00:35	00:46	03:02	03:03	DNA	DNA
199	Flaming Boxes (plastic)	9	DNA	DNA	04:03	04:01	DNA	DNA	00:37	00:50	02:41	02:47	02:48	02:48
200	Flaming Boxes (plastic)	9	DNA	DNA	03:57	02:52	DNA	DNA	01:08	01:10	02:39	02:40	03:00	03:05
		Average	06:05	04:16	03:43	03:46	DNA	DNA	01:19	01:28	02:47	02:50	02:54	02:56
		STDEV			00:24	00:40			01:07	01:07	00:13	00:12	00:08	00:12
203	Smoldering Cable	9	07:50	DNA	07:44	06:20	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
204	Smoldering Cable	9	06:37	DNA	06:57	04:56	DNA	DNA	DNA	DNA	08:23	DNA	DNA	DNA
		Average	07:14	DNA	07:21	05:38	DNA	DNA	DNA	DNA	08:23	DNA	DNA	DNA
		STDEV	00:52		00:33	00:59								

Table 75 — VSD-8 Smoke Alarm Times for Flaming Box Fires, Flaming Boxes Filled with Plastic Bubble Wrap, and Smoldering Cable Fires at Location 9 in the Passageway

Test	Source	Location	VSD-8 Alarm			
			Camera 1 Near Field	Camera 3 Near Field	Camera 4 Far Field	Camera 6 Far Field
195	Flaming Boxes	9	DNA	DNA	DNA	DNA
196	Flaming Boxes	9	DNA	DNA	DNA	DNA
197	Flaming Boxes	9	DNA	04:38	DNA	04:37
191	Flaming Boxes	9	DNA	DNA	DNA	DNA
192	Flaming Boxes	9	DNA	DNA	DNA	DNA
		Average	DNA	04:38	DNA	04:37
		STDEV				
190	Flaming Boxes (plasic)	9	DNA	DNA	DNA	DNA
198	Flaming Boxes (plastic)	9	03:48	02:33	03:42	02:32
199	Flaming Boxes (plastic)	9	DNA	DNA	DNA	DNA
200	Flaming Boxes (plastic)	9	02:47	DNA	02:50	DNA
		Average	03:18	02:33	03:16	02:32
		STDEV	00:43		00:37	
203	Smoldering Cable	9	10:09	07:58	10:08	08:03
204	Smoldering Cable	9	DNA	DNA	DNA	DNA
		Average	10:09	07:58	10:08	08:03
		STDEV				

Table 76 — Smoke Detector Activation Times for the EST and Notifier Systems for Flaming Boxes, Flaming Boxes Filled with Plastic Bubble Wrap, and Smoldering Cable Fires at Location 9 in the Passageway

Test	Source	Location	Notifier Alarms		EST Alarms	
			Notifier Ion	Notifier Photo	EST Ion	EST Photo
195	Flaming Boxes	9	02:33	04:51	01:08	DNA
196	Flaming Boxes	9	02:28	DNA	01:14	DNA
197	Flaming Boxes	9	02:20	DNA	00:54	DNA
191	Flaming Boxes	9	02:53	DNA	01:25	DNA
192	Flaming Boxes	9	02:26	02:08	01:05	DNA
		Average	02:32	03:29	01:09	DNA
		STDEV	00:13	01:55	00:11	
190	Flaming Boxes (plastic)	9	00:57	04:09	00:48	04:08
198	Flaming Boxes (plastic)	9	02:07	03:22	00:51	03:37
199	Flaming Boxes (plastic)	9	02:52	03:40	00:59	03:51
200	Flaming Boxes (plastic)	9	02:38	03:38	01:23	03:58
		Average	02:09	03:42	01:00	03:53
		STDEV	00:51	00:20	00:16	00:13
203	Smoldering Cable	9	DNA	18:09	DNA	11:49
204	Smoldering Cable	9	DNA	11:50	22:48	09:31
		Average		15:00	22:48	10:40
		STDEV		04:28		01:38

5.8.3 Source Location 8 Tests

Tables 77 to 80 present the alarm times for the VID systems and spot-type detection systems for smoldering and flaming cable fires at Location 8 (see Figure 18). Location 8 is unique in that it consisted of small sources able to fit in the cable tray in the overhead of the passageway. Table 77 lists the SFA smoke and fire algorithm alarm times. No SFA fire algorithm alarms occurred due to the overhead obstructions that blocked the fire from the line of sight of the cameras. However, as noted for Test 188, two fire alarms did occur; but these were due to blooming around the light fixtures. Blooming is an effect of smoke diffracting light around the light fixture, causing a brightening of the video image around the fixture. Table 78 lists the SigniFire smoke, fire and offsite algorithm results for the smoldering and flaming cable fires at Location 8. Similar to the SFA system, the SigniFire offsite and fire alarms did not alarm to the any of the fires at Location 8 due to the obscured view of the small cable fires.

As noted for the other passageway tests, the smoke algorithm alarms showed quite varied results, even for collocated cameras. For example the SFA alarm times between Camera 4 and Camera 6 for the smoldering cable fires varied from 3 to 25 minutes (Table 77). Despite the variations in response, the smoldering cable fires were detected in almost every video image by the SFA and SigniFire systems; the VSD-8 system, however, did not alarm to any of these smoldering cable fires. Interestingly, the VSD-8 did alarm to the flaming cable fires that produced very little smoke, particularly in comparison to the smoldering cable fires. [These reported alarms may be associated more with the intermittent presence of the test operator who had to enter the passageway to ignite the cables after they had preheated and started to smoke. In way of comparison, the flaming cable fires produced more visible smoke than the box fires. The SFA smoke algorithm alarmed to almost every video image of all the flaming cable fires (16 of 20). The SigniFire smoke algorithm was not as effective; it alarmed for 8 of the 20 video images.

Table 80 lists the spot-type detector activation times for sources at Location 8. The sources consisted of flaming and smoldering cable. In the previous test, the spot-type detectors were usually divided by detection mode (i.e., ion vs. photo) however, at Location 8 the majority of alarms occurred for the EST detectors with the EST photo and ion detectors accounting for eight of 10 alarms. The spot-type detectors as a whole performed poorly only alarming to 50% of the flaming cable fires. The spot-type detectors demonstrated improved performance with all but two (Notifier Ion and EST Ion for test 193) out of 12 possible alarms activating to the smoldering cable.

Table 77 — SFA Smoke and Fire Alarm Times for Smoldering and Flaming Cable Fires at Location 8 in the Overhead

			SFA Smoke Algorithms				SFA Fire Algorithms			
Test	Source	Location	Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field	Camera 1 Far Field	Camera 3 Far Field	Camera 4 Near Field	Camera 6 Near Field
194	Flaming Cable	8	05:19	05:34	12:01	11:18	DNA	DNA	DNA	DNA
218	Flaming Cable	8	05:41	06:04	05:44	05:54	DNA	DNA	DNA	DNA
220	Flaming Cable	8	04:53	04:50	DNA	08:22	DNA	DNA	DNA	DNA
217	Flaming Cable	8	03:57	03:48	05:42	07:14	DNA	DNA	DNA	DNA
		Average	04:58	05:04	07:49	23:12	DNA	DNA	DNA	DNA
		STDEV	00:45	00:59	03:38	32:05				
188	Smoldering Cable	8	02:10	08:52	38:17	59:55	DNA	DNA	15:51	14:36
189	Smoldering Cable	8	12:54	12:40	28:43	03:29	DNA	DNA	DNA	DNA
193	Smoldering Cable	8	03:25	03:43	04:27	07:21	DNA	DNA	DNA	DNA
		Average	06:10	08:25	43:49	23:35	DNA	DNA	15:51	14:36
		STDEV	05:52	04:30	48:42	31:31				

Table 78 — Signifire Offsite, Smoke, and Fire Activation Times for Flaming and Smoldering Cable Fires at Location 8 in the Overhead of the Passageway

			SigniFire Smoke Algorithm				SigniFire Fire Algorithm				SigniFire Off-site Algorithm			
Test	Source	Location	Camera 1 Near Field	Camera 3 Near Field	Camera 4 Far Field	Camera 6 Far Field	Camera 1 Near Field	Camera 3 Near Field	Camera 4 Far Field	Camera 6 Far Field	Camera 1 Near Field	Camera 3 Near Field	Camera 4 Far Field	Camera 6 Far Field
194	Flaming Cable	8	DNA	05:58	04:46	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
218	Flaming Cable	8	DNA	DNA	05:25	07:37	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
220	Flaming Cable	8	DNA	DNA	09:58	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
217	Flaming Cable	8	DNA	13:54	13:35	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
		Average	DNA	09:56	08:26	07:37	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
		STDEV		05:37	04:08									
188	Smoldering Cable	8	11:02	09:07	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
189	Smoldering Cable	8	09:01	05:34	28:19	19:06	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
193	Smoldering Cable	8	12:40	04:33	03:22	04:10	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
		Average	10:54	06:25	15:51	11:38	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
		STDEV	01:50	02:24	17:39	10:34								

Table 79 — VSD-8 Smoke Alarm Activation Times for a Smoldering Cable Fires and Flaming Cable Fires at Location 8 in the Overhead of the Passageway

			VSD-8 Alarm			
Test	Source	Location	Camera 1 Near Field	Camera 3 Near Field	Camera 4 Far Field	Camera 6 Far Field
194	Flaming Cable	8	DNA	06:02	06:17	DNA
218	Flaming Cable	8	DNA	DNA	DNA	DNA
220	Flaming Cable	8	DNA	DNA	03:23	03:19
217	Flaming Cable	8	07:59	DNA	18:25	19:35
		Average	07:59		10:54	11:27
		STDEV			10:38	11:30
188	Smoldering Cable	8	DNA	DNA	DNA	DNA
189	Smoldering Cable	8	DNA	DNA	DNA	DNA
193	Smoldering Cable	8	DNA	DNA	DNA	DNA
		Average				
		STDEV				

Table 80 — Smoke Detector Activation Times for the EST and Notifier Systems for Flaming Cable Fires and Smoldering Cable Fire at Location 8 in the Overhead of the Passageway

			Notifier Alarms		EST Alarms	
Test	Source	Location	Notifier Ion	Notifier Photo	EST Ion	EST Photo
194	Flaming Cable	8	20:13	10:01	08:06	13:25
218	Flaming Cable	8	DNA	DNA	08:03	19:41
220	Flaming Cable	8	DNA	DNA	05:14	08:22
217	Flaming Cable	8	DNA	DNA	06:20	09:09
		Average	DNA	DNA	06:32	12:24
		STDEV			01:25	06:19
188	Smoldering Cable	8	36:19	16:13	25:19	11:22
189	Smoldering Cable	8	25:31	21:01	20:31	10:10
193	Smoldering Cable	8	DNA	04:13	DNA	04:03
		Average	30:55	13:49	22:55	08:32
		STDEV	07:38	08:39	03:24	03:55

5.8.4 Nuisance Source Tests

In addition to the fire sources tested in the passageway, selected nuisance sources were also tested. Tables 81 to 84 provide the results of the VID systems and spot-type detection systems exposed to the nuisance sources in the passageway. The nuisances sources were repeated at several locations in the compartment. The multi-algorithm VID systems had few nuisance alarms. The SFA system alarmed to the aerosol nuisance sources with the smoke algorithm for multiple camera images, and it also alarmed with the fire algorithm in one camera view to multiple people in the space with flashbulbs. The SigniFire system alarmed to two nuisance sources, the aerosol and the flashlight in only one camera video (Table 82). These results are comparable to those obtained in the larger compartment. The passageway nuisance source test results for the VSD-8 system were also similar to the larger compartment tests. As Table 83 shows, the VSD-8 alarmed for every nuisance source and usually for multiple camera videos. As noted in Section 5.7, because many of the nuisance sources involved people moving within the space, it is difficult to determine whether the nuisance alarms were due to the source being tested or the presence of a person.

Table 84 presents the responses of the spot-type smoke detection systems to the nuisance sources located in the passageway. The spot-type detectors did not alarm to any of the nuisance sources. Except for the aerosol, the smoke detectors were inherently immune to the sources tested. As with the compartment tests, the nuisance sources in the passageway were designed to primarily challenge the VID systems.

Table 81 — SFA Smoke and Fire Algorithm Responses to Nuisance Sources in the Passageway

Test	Source	SFA Smoke Algorithms				SFA Fire Algorithms			
		Camera 1	Camera 3	Camera 4	Camera 6	Camera 1	Camera 3	Camera 4	Camera 6
225	Aerosol	DNA	04:13	05:48	05:49	DNA	DNA	DNA	DNA
228	Aerosol	02:48	DNA	05:47	DNA	DNA	DNA	DNA	DNA
209	Flash Bulb	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
226	Flash Bulb	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
207	Flash Light	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
208	Flash Light	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
205	Man in Compartment	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
206	Man in Compartment	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
210	Multiple people working and flash bulb	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
211	Multiple people working and flash bulb	DNA	DNA	DNA	DNA	DNA	00:51	DNA	DNA
212	Sunlight	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
213	Sunlight	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
214	Sunlight	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
222	Waving White shirt	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
227	Waving White shirt	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA

Table 82 — Signifire Smoke, Fire and Offsite Algorithm Responses to Nuisance Sources in the Passageway

Test	Source	SFA Smoke Algorithms				SFA Fire Algorithms			
		Camera 1	Camera 3	Camera 4	Camera 6	Camera 1	Camera 3	Camera 4	Camera 6
225	Aerosol	DNA	04:13	05:48	05:49	DNA	DNA	DNA	DNA
228	Aerosol	02:48	DNA	05:47	DNA	DNA	DNA	DNA	DNA
209	Flash Bulb	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
226	Flash Bulb	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
207	Flash Light	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
208	Flash Light	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
205	Man in Compartment	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
206	Man in Compartment	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
210	Multiple people working and flash bulb	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
211	Multiple people working and flash bulb	DNA	DNA	DNA	DNA	DNA	00:51	DNA	DNA
212	Sunlight	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
213	Sunlight	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
214	Sunlight	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
222	Waving White shirt	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
227	Waving White shirt	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA

Table 83 — VSD-8 Responses to Nuisance Sources in the Passageway

Test	Source	VSD-8 Alarm			
		Camera 1	Camera 3	Camera 4	Camera 6
225	Aerosol	01:51	DNA	06:29	DNA
228	Aerosol	DNA	DNA	DNA	DNA
209	Flash Bulb	02:24	00:36	DNA	00:34
226	Flash Bulbs	02:50	DNA	03:25	DNA
207	Flash Light	DNA	00:21	DNA	00:20
208	Flash Light	DNA	DNA	DNA	02:01
205	Man in Compartment	12:15	DNA	00:09	00:09
206	Man in Compartment	DNA	10:51	02:41	10:51
210	Multiple people working and flash bulb	DNA	01:28	DNA	01:28
211	Multiple people working and flash bulb	02:13	02:14	02:10	02:14
212	Sunlight	03:44	03:44	03:39	03:43
213	Sunlight	03:32	DNA	03:29	DNA
214	Sunlight	05:52	DNA	05:14	05:52
222	Waving White shirt	DNA	DNA	02:57	DNA
227	Waving White shirt	DNA	00:44	00:46	00:43

Table 84 — Spot-Type Smoke Detection System Responses to Nuisance Sources in the Passageway

Test	Source	Notifier Alarms		EST Alarms	
		Notifier Ion	Notifier Photo	EST Ion	EST Photo
225	Aerosol	DNA	DNA	DNA	DNA
228	Aerosol	DNA	DNA	DNA	DNA
209	Flash Bulb	DNA	DNA	DNA	DNA
226	Flash Bulbs	DNA	DNA	DNA	DNA
207	Flash Light	DNA	DNA	DNA	DNA
208	Flash Light	DNA	DNA	DNA	DNA
205	Man in Compartment	DNA	DNA	DNA	DNA
206	Man in Compartment	DNA	DNA	DNA	DNA
210	Multiple people working and flash bulb	DNA	DNA	DNA	DNA
211	Multiple people working and flash bulb	DNA	DNA	DNA	DNA
212	Sunlight	DNA	DNA	DNA	DNA
213	Sunlight	DNA	DNA	DNA	DNA
214	Sunlight	DNA	DNA	DNA	DNA
222	Waving White shirt	DNA	DNA	DNA	DNA
227	Waving White shirt	DNA	DNA	DNA	DNA

The passageway provided a space with a different aspect ratio than used in any prior tests. The change in dimensions narrowed the field of view of the cameras. In general, the VID systems had similar alarm responses to fires, such as the flaming boxes and smoldering cable fires, in the passageway and in the compartment. For the flaming boxes with plastic, the systems had similar detection results in the passageway and the compartment, except that the SFA smoke algorithm alarmed to the fires faster by about 1 to 2 minutes. Overall, the passageway did not present any clearly identifiable issues for the VID systems that were not identified in the compartment tests for either fires or nuisance sources.

5.9 Analysis of Long Wavelength Cameras with Pair-wise Combinations with Regular Cameras

One objective of the test series was the evaluation of the long wavelength video system. This test series provides an opportunity to evaluate the performance of the nightvision cameras and the NRL LWVD system in comparison to, and in combination with, the regular cameras and commercial VID systems. In this analysis, the number of alarms for different source and false events were tallied for the long wavelength cameras and compared with similarly generated numbers for the regular cameras. In addition, the number of alarms was tallied for pairs of long wavelength and regular cameras combined with simple Boolean logic. Video images from the nightvision cameras were analyzed by the commercial VID systems and the NRL LWVD system. Only results from nightvision cameras analyzed by the NRL LWVD system are used in this analysis and compared to results from the regular cameras analyzed by the commercial VID systems. A more comprehensive analysis of the video systems comparing nightvision and regular cameras in several combinations is forthcoming for use in the integration of sensors and video systems for the Volume Sensor program.

The analysis was limited to tests conducted in Compartment 1 for which there are results from both the nightvision and regular cameras. For these tests, two long wavelength cameras, numbers 7 and 8, were collocated with two regular cameras at locations 1 and 4, as shown in Figure 12. Only tests with optimal video camera settings were included in this analysis. Further, individual tests were removed from the pair analysis if either of the VID systems analyzing the cameras was not enabled. Thus, the number of tests used in the analysis varied slightly with VID system and camera type.

Tests were also separated into three event types or categories: labeled "smoldering" for fires dominated by smoke, "flaming" for fires with flames present, and "false" for nuisance events, as described in Tables 8 and 9. Smoldering and flaming events were combined into a fourth category, labeled "combined fire" and representing all fire sources, for comparison of the probability of event detection (P_D) to the probability of false alarm (P_{FA}) for the VID systems. Several smoldering fires transitioned to flaming fires during the test. These transitioned events were included only in the smoldering and combined fire event categories.

For the initial evaluation of the long wavelength video system, the number of alarms for each event category were tallied for the nightvision cameras 7 and 8, and analyzed with the NRL LWVD system. The results are presented in the "LWVD" columns of Table 85. Here, the values in the "Alarms" column are the number of tests for which the video system registered an alarm for that event type. The values in the "Tests" column are the number of tests with that

event type for which the video system and corresponding camera were enabled. The "Ratio" column lists as a percent the fraction "Alarms" / "Tests." For comparison, the number of alarms for each event category were tallied for the regular cameras 1 and 4, collocated with the nightvision cameras, and analyzed with the Fastcom Smoke and Fire Alert (SFA), the Axon-X SigniFire (SF), and the Fire Sentry VSD-8 (VSD), commercial video systems. These results are also listed in Table 85. Further, a plot comparing the fraction of combined fire events (P_D) to the fraction of false detections (P_{FA}) for each system is shown in Figure 30. Larger P_D and smaller P_{FA} values indicate better system performance. A box delineating the region of performance better than 95% P_D and 5% P_{FA} is shown (95/5 box) for reference in Figure 30. A line denoting the performance of a system based solely on random chance is also shown (50/50 line.)

The number of alarms from the two collocated camera pairs were grouped together by video system pair for both logical combinations, and similarly grouped for the two opposite located camera pairs. The P_D versus P_{FA} points for the collocated pairs comparing the fraction of combined fire events to the fraction of false detections for each video system pair and logical combination are also shown in Figure 30. For the logical *OR* combination, the points for the three video system pairs increase in both the P_D and P_{FA} directions. For the logical *AND* combination, the P_D versus P_{FA} points for the system pairs decrease in both directions. This mismatch of percentages for the *AND* and *OR* combinations is consistent with the complementary detection capabilities observed for regular and nightvision cameras in reference [7].

Comparing the P_D and P_{FA} percentages for the logical *OR* combination to the percentages from the commercial video systems shows that the *OR* combination of regular and nightvision cameras enhances the probability of detection by 5% to 25%, depending on the system. The minimum trade-off for the improved P_D values, however, is an increase of the probability of false alarms by approximately 15%. These increases were seen whether or not the cameras were collocated, or located in opposite corners of Compartment 1.

Table 85 — Comparison of Collocated Regular and Nightvision Cameras Analyzed by the Specified Systems for Detection of Smoldering, Flaming, and False Events

Collocated Pairs of Cameras: Regular (SFA, SF, VSD systems) & Nighvision (NRL LWVD system)												
Event Type	**SFA**			**SF**			**VSD**			**LWVD**		
	Alarms	Tests	Ratio	Alarms	Tests	Ratio	Alarms	Tests	Ratio	Alarms	Tests	Ratio
Smoldering	70	93	75%	77	99	78%	47	99	47%	53	93	57%
Flaming	44	56	79%	48	58	83%	31	58	53%	53	56	95%
Combined Fire	114	149	77%	125	157	80%	78	157	50%	106	149	71%
False	20	81	25%	15	81	19%	40	81	49%	23	81	28%

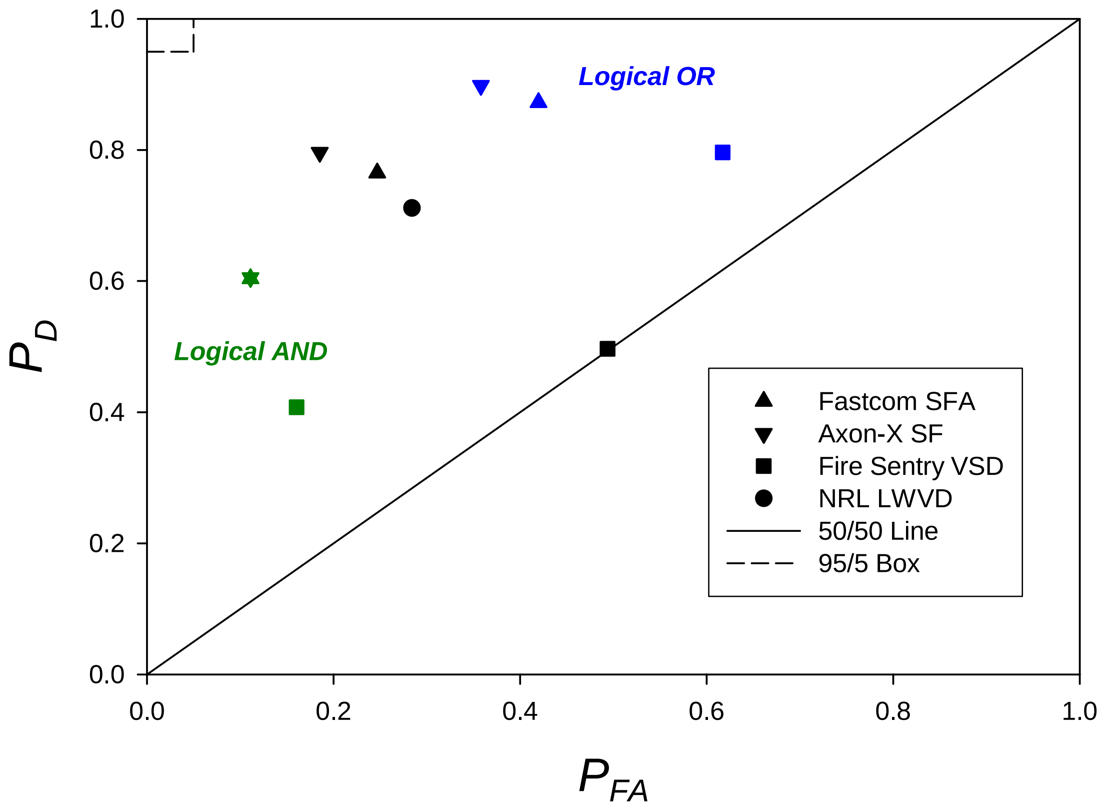

Fig. 30 — P_D versus P_{FA} plot for regular cameras analyzed by the commercial VID systems and the nightvision cameras analyzed by the NRL LWVD system (black points). P_D versus P_{FA} points for the three Boolean-combined, collocated regular and nightvision pairs are also shown (green and blue points)

Next, comparing the P_D and P_{FA} percentages for the logical *AND* combination to the percentages from the commercial video systems demonstrates that the *AND* combination of regular and nightvision cameras improves the probability of false alarm by 10% to 35%, again depending on the system. Here, the minimum trade-off for better P_{FA} values is a decrease in the probability of detection by approximately 15% for either the Fastcom or the AxonX system. These decreases were also seen whether or not the cameras were collocated or opposite located in Compartment 1.

Some caveats for the results of the analysis should be noted. The selection of tests was not identical for each video system or camera type. Although this could be a source of bias in the P_D and P_{FA} values for or against a system, the difference in the total number of tests for each system / camera combination is only 8, and is much smaller than the number of tests—approximately 150—used in the analysis. In addition, the number of source events and false events in or out of the line-of-sight or field-of-view of the cameras depends on the locations and proximity of the events and obstructions to the cameras. No effort was made to analyze the effect of source or obstruction locations at this time.

The analysis summarized by Table 85 also lists P_D percentages separately for smoldering and flaming type events for each VID system. Table 85 indicates the P_D values for regular cameras by themselves differ by about 5%, less for smoldering than flaming events. For nightvision cameras, the P_D percentage for smoldering events is roughly 35% less than for flaming events. Compared to the SFA and SigniFire systems, smoldering event detection with the NRL LWVD system is about 20% lower while flaming event detection is about 15% higher. The difference for the nightvision cameras analyzed by the NRL LWVD system is expected as the design of the luminosity algorithm emphasized detection of flame emission both in and out of the line-of-sight of an individual camera. This detection imbalance between smoldering and flaming events persisted after the commercial systems were combined with the NRL LWVD system, though the magnitude of the difference was reduced to about 25%. Closer inspection of the numbers, however, showed that the P_D rates for flaming events in the *AND* combination are only about 5% lower than the P_D rates for flaming events with regular cameras listed in Table 85. Given that the P_{FA} percentages with the *AND* camera combination are about 10% lower than without, this represents some improvement and is evidence that the NRL LWVD system detects nearly all the flaming events detected by the commercial systems, but alarms on a subset of false event tests complementary to the commercial systems.

To summarize the results of the analysis, the P_D / P_{FA} performance for a single regular camera analyzed by the SFA and SigniFire commercial video systems is approximately 80% / 20%. For a single nightvision camera analyzed by the NRL LWVD video system, the P_D / P_{FA} performance is roughly 70% / 30%. Combining regular and nightvision cameras into pairs using simple *OR* logic results in a P_D / P_{FA} performance of about 90% / 40%; using *AND* logic reduces this to about 60% / 10%. There is some evidence that combining regular and nightvision camera pairs with *AND* logic between the flaming algorithm of the SFA or SigniFire system and the NRL LWVD system may yield a P_D / P_{FA} performance closer to 80% / 10%. Essentially no performance difference was observed between collocated and opposite located camera pairs. Comparison of the results presented here to those from pairs of regular cameras, and to those from the nightvision cameras analyzed by the commercial video systems remains to be explored.

Finally, the quantitative results presented here need to be qualified by consideration of the following factors: the test matrix was designed to evaluate the effects of changes in camera settings and lighting conditions on the performance of the regular video cameras analyzed by the commercial video systems and not to compare the merits of the nightvision cameras to the regular video cameras. In addition, the test matrix was not a balanced reflection of anticipated shipboard threats. For example, no adjacent compartment fires were included in the test matrix. The results also do not include any analysis of the response times of the different systems, or the dependence of flaming event detection on camera field-of-view. Lastly, improvements in the luminosity algorithm or the detection algorithms of the commercial systems could significantly impact the results.

5.10 SBVS Test bed Results

A preliminary examination of the data from the Volume Sensor 2 (VS2) Test Series, was made of thirty-three candidate tests, which were identified from the total set of 253 tests conducted. The candidate tests, listed in Table 86 below, were selected to be representative of the variety of sources and nuisances tested in this test series. In addition, tests were selected to allow for comparison between similar sources both in and out of the Test bed's field of view (FOV) and also for smoldering sources, some but not all of which transitioned to flaming during the tests. Columns 1 and 2 of Table 86 indicate the VS2 test number for each test and the corresponding SBVS Test bed data root file name.[1] Column 3 lists the Source Type, and Columns 4 and 5 indicate whether or not each test was within the FOV of the Test bed and if the source transitioned during the test (defined as yes for flaming sources), respectively.

[1]See reference 8 for a discussion of the Test bed file structures

Table 86 — VS2 SBVS Test Bed Candidate Tests

Sources				
VS2 Test #	**SigmaPlot DL Filename**	**Source Type**	**In FOV? [a]**	**Transitioned?**
007	Jul232003_112202.JNB	Flaming Bedding	No	Yes
019	Jul292003_095917.JNB	Flaming Boxes w/ Paper Filling	No	Yes
010	Jul232003_151943.JNB	Flaming Boxes w/ Paper Filling	Yes	Yes
198	Nov102003_143355.JNB	Flaming Boxes w/ Plastic Filling	Yes	Yes
194	Nov102003_094821.JNB	Flaming Cable Bundle	No	Yes
217	Nov142003_101459.JNB	Flaming Cable Bundle	Yes	Yes
120	Sep182003_133353.JNB	Flaming Trash Can	No	Yes
121	Sep182003_141133.JNB	Flaming Trash Can	Yes	Yes
165	Oct232003_165200.JNB	Smoldering Cables	No	No
223	Nov142003_154727.JNB	Smoldering Cables	Yes	Yes
181	Oct282003_111335.JNB	Smoldering Circuit Boards	No	No
177	Oct272003_154425.JNB	Smoldering Laundry	No	Yes
114	Sep082003_182121.JNB	Smoldering Laundry (transitioned)	No	Yes
064	Aug202003_151703.JNB	Smoldering Laundry	Yes	No
096	Sep042003_164111.JNB	Smoldering Laundry (transitioned)	Yes	Yes
168	Oct242003_095036.JNB	Smoldering Mattress	No	Yes
158	Sep302003_151718.JNB	Smoldering Monitor	No	Yes
178	Oct272003_165406.JNB	Smoldering Trash	No	Yes
180	Oct282003_104335.JNB	Smoldering Wire	No	No
102	Sep052003_154457.JNB	Flaming Wood Crib	No	Yes
			Total	**20**
Nuisances				
VS2 Test #		**Source Type**	**In FOV?**	**Transitioned?**
133	Sep242003_104803.JNB	Aerosol	?	No
152	Sep302003_103617.JNB	Toast	No	No
136	Sep242003_140145.JNB	Toast, Burnt	No	No
155	Sep302003_134829.JNB	Cutting Steel	Yes	No
156	Sep302003_141409.JNB	Cutting Steel	No	No
209	Nov122003_160146.JNB	Flash Bulb	?	No
207	Nov122003_152802.JNB	Flash Light	?	No
131	Sep242003_100748.JNB	People Working	?	No
141	Sep252003_065636.JNB	Sunlight	No	No
212	Nov132003_082340.JNB	Sunlight	No	No
145	Sep302003_082827.JNB	Waving White Shirt	?	No
137	Sep242003_144239.JNB	Welding	Yes	No
154	Sep302003_132510.JNB	Welding (Stick)	No	No
			Total	**13**

[a] A result of "?" in the "In FOV?" column indicates that the source was either moving about the compartment during the test or the precise location of the source as a function of time is unknown.

[1] See reference 8 for a discussion of the Test bed file structures

The SBVS Test bed acquires and records 25 quantities at 1-10 Hz each, necessitating mechanisms for displaying the data in a manner that allows for analysis and processing. As a guide for the following discussion of how SBVS Test bed data is handled and ultimately processed, Figure 31 presents all of the SBVS Test bed data for test VS2-010 in the form of time series graphs. Test VS2-010 was a paper-filled cardboard box fire source positioned within the Test bed FOV. As previously discussed in the experimental section of this report and Reference 9, data collection for each test began approximately two minutes prior to source ignition and all times are reported as actual time of day, not elapsed time. The time of day of the ignition event for each test is reported in the Master Table on the CD attached to this document.

The current detectors included in the Test bed are listed in Table 87 along their associated symbols or abbreviations and the detector output ranges and units. For each test, the various detector outputs are plotted in groups either by detector unit (e.g., EyeSpy OFD) or detector type (e.g., IR sensors centered at 4.3 microns (μm)). All sub-panels display sensor outputs as a function of time. The first sub-panel shows the data from the UV detectors, the OmniGuard UV output (Omni UV), the EyeSpy UV output (EyeSpy UV), and two PMT channels (307 and 260 nm). The PMT signal has been baseline-corrected and inverted for viewing purposes.

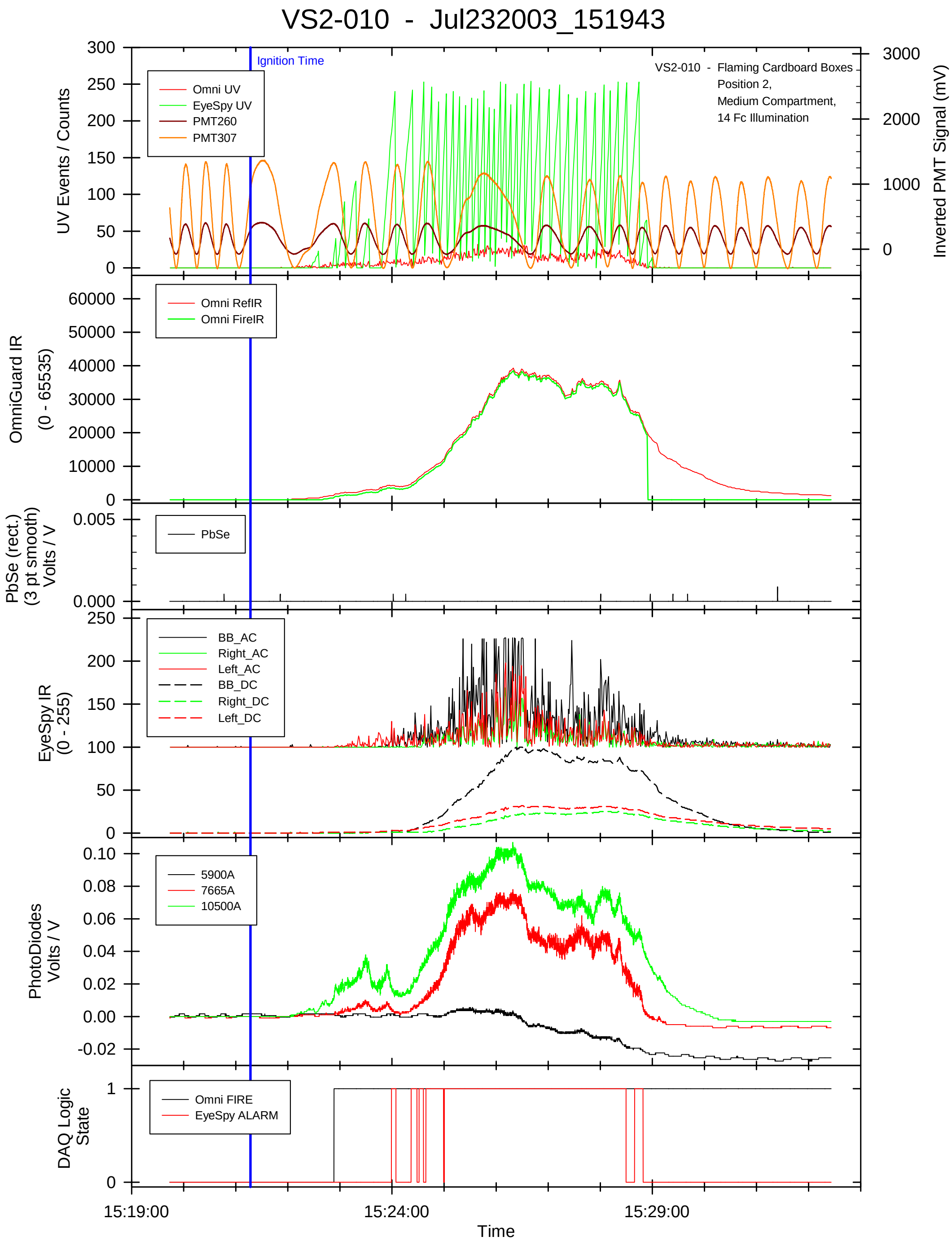

Fig. 31 — SBVS Test bed all-in-one output presentation for Test 010

Table 87 — SBVS Test bed Configuration and Data Ranges

SBVS Test bed Detector / Nominal $_{0}$	**Symbol or Abbreviation**	**Range**	**Units**
SubPanel 1			
OmniGuard UV	Omni UV, OG UV	0 – 65536	counts
EyeSpy UV	ES UV	0 – 255	counts
260 nm PMT	PMT260	-3,000 – 3,000 [a]	mV
307 nm PMT	PMT307	-3,000 – 3,000 [a]	mV
SubPanel 2			
OmniGuard Reference IR (4.3 m)	Omni RefIR, OG IR	0 – 65536 [b]	counts
OmniGuard Fire IR (4.3 m)	Omni FireIR	0 – 65536	counts
SubPanel 3			
PbSe (4.3 m)	PbSe	0.000 – 0.005 [c]	Volts
SubPanel 4			
EyeSpy Broadband IR, AC coupled	BB_AC, ES BB AC	128 – 255	counts
EyeSpy Broadband IR, DC coupled	BB_DC, ES BB DC	0 – 255	counts
EyeSpy Left (4.3 m) IR, AC coupled	Left_AC, ES L AC	128 – 255	counts
EyeSpy Left (4.3 m) IR, DC coupled	Left_DC, ES L DC	0 – 255	counts
EyeSpy Right (4.3 m) IR, AC coupled	Right_AC, ES R AC	128 – 255	counts
EyeSpy Right (4.3 m) IR, DC coupled	Right_DC, ES R DC	0 – 255	counts
SubPanel 5			
Sodium PD (590.0 nm)	5900A, Na	-0.05 to 0.10 [b]	Volts
Potassium PD (766.5 nm)	7665A, K	-0.05 to 0.10 [b]	Volts
NIR PD (1050.0 nm)	10500A, NIR	-0.05 to 0.10 [b]	Volts
SubPanel 6			
OmniGuard Flame Alarm	Omni Fire	0,1	Boolean
EyeSpy Flame Alarm	EyeSpy Alarm	0,1	Boolean

[a] Raw signal is baseline corrected and then inverted to yield positive-going signal.
[b] Raw signal is baseline corrected.
[c] Raw signal is baseline corrected, absolute-valued, and 3-point smoothed to produce a positive-going (uni-polar) signal.

The second sub-panel shows the OmniGuard Reference IR (Omni RefIR) and Fire IR (Omni FireIR). The RefIR signal has been baseline-corrected. Sub-panel three shows the PbSe output. Since the PbSe detector is mechanically chopped and has an AC-coupled output, the signal has been baseline-corrected, absolute-valued, and 3-point smoothed.

Sub panel 4 shows the baseline-corrected AC- and DC-coupled outputs of the EyeSpy broad band IR power case detector (EyeSpy BB_AC, EyeSpy_BB_DC), and left (EyeSpy Left_AC, EyeSpy Left_DC) and right (EyeSpy Right_AC, EyeSpy Right_DC) 4.3 μm IR detectors. Sub-panel five shows the baseline-corrected output voltages from sodium (5987A), potassium (7665A), and NIR (10500A) photodiodes. The sixth sub-panel shows the COTS OmniGuard and EyeSpy alarm status. A state value of 0 is the normal condition. A state value of 1 indicates either an Omni FIRE or EyeSpy ALARM event.

Similar plots are provided on the report CD, in Appendix C, for all 33 SBVS Test bed Candidate Tests from the VS2 Test Series along with the raw data files. The results of the baseline subtraction and filtering generate values for each sensor channel which can be evaluated as a function of time or for in comparison with other channels for event detection and classification (fire, smoke, and nuisance in this case). This level of pre-processing, along with a common output scaling is necessary for inter-system comparison or inclusion/fusion with the other subsystems being evaluated for inclusion in the final Volume Sensor prototype.

While the PMT and PbSe data were collected and are provided here, these sensors did not provide any improvement over the similar commercial sensors in the OFDs. The PbSe detector performance was disappointing, with little or no observable above-baseline signal detected. The in-house UV sensors also did not work better than the commercially available alternatives so that analysis of the PMT data was not pursued further in the current analysis. The fluorescent lights in the test compartment emit strongly in the UV, to the point of overwhelming the blocking capacity of the bandpass filters installed on the PMTs with near-band radiation and saturating the detectors. Covering the lights with clear plastic sleeves similar to those used to generate the red lighting condition of test VS2-095 greatly moderated the effect of the lighting. However, the PMTs still did not perform very well, not nearly as well as the UV sensors in the OFDs.

Several composite metrics were developed from the available Test bed data for comparison with the VIDS system event detection and alarm times. The two commercial OFDs that are components of the SBVS Test bed have internal flame event detection logic that operates in parallel with the recording of raw sensor data by the Test bed. For metrics that compared detector readings collected at different rates, the data streams were dithered, or artificially reduced in data frequency to match the slowest data rate, no less than 1 Hz. The proprietary embedded logic compares the sensor values from the UV and IR detectors and generates an alarm event when specific criteria are met.

In the spirit of the multi-spectral approach to flame event detection used in the OFDs, the SBVS Test bed data will be analyzed in groups as composite values which should provide enhanced classification / nuisance rejection abilities. A first selection of composite values for

evaluation was devised and tested against the VS2 Candidate tests. The two classes of composite quantities, nominally termed fire and smoke composites based on the initial analysis of the data, are listed in Table 88 along with the raw channels which are used to produce these values. The composite quantities are, in general, ratios of the two values indicated in Table 88. One exception is the albedo-like quantity, hereafter referred to as albedo or $A(X_i)$, where the albedo is defined as:

$$A(X_1) = \frac{I(X_1)}{\sum I(X_i)}$$

where $A(X_i)$ is the albedo of photodiode (PD) X_i, and $I(X_i)$ is the PD intensity in baseline-corrected volts, and X_i is *i*th PD. Another exception is the Eyespy IR ratio composite, which is the ratio of the sum of 4.3 µm detectors (left and right) to the broadband IR detector outputs, or

$$Eyespy\_IR\_Ratio = \frac{I\big(4.3\mu m(Left)\big) + I\big(4.3\mu m(Right)\big)}{I\big(BroadBand\big)}$$

The composite values were calculated and compared to empirically developed threshold values based on a subset of the VS2 Candidate tests. For each data point in the time series, any composite value meeting the threshold criteria listed in Table 88 was recorded along with the corresponding time stamp. These time-of-day timestamps were then converted to time from ignition using the recorded ignition time of day. This allowed for direct comparison to the VIDS alarm times. At this initial stage, there was no persistence requirement applied; a single reading above threshold generated an event.

Persistence will be considered in future refinements of the Test bed event detection / classification algorithms.

Table 88 — SBVS Test bed Composite Values v.1

Composite	TestBed Channels used	Threshold Values Used	Units (if any)
FIRE Composites			
Albedo FIRE	Na, K, and NIR PDs	A(NIR)>0.5, A(K)>0.2, A(Na)<0.25, A(NIR)>A(K)>A(Na)	none
EyeSpy IR Ratio FIRE	EyeSpy DC IR	5.0 > (ES_L+ES_R)/ES_BB > 0.0	none
OmniGuard UV/IR FIRE	OmniGuard UV, RefIR	OG_UV/OG_RefIR > 0.001	none[a]
EyeSpy UV/IR FIRE	EyeSpy UV_Count, EyeSpy DC (L+R)	ES_UV/(ES_L+ES_R) > 0.15	none[a]
OmniGuard IR/NIR FIRE	OmniGuard RefIR, NIR PD	1000 > OG_RefIR/(1000*NIR_PD) > 300	counts/mV
OmniGuard UV/NIR FIRE	OmniGuard UV, NIR PD	OG_UV/NIR_PD > 100	counts/mV
OmniGuard UV/Na FIRE	OmniGuard UV, Na PD	OG_UV/Na_PD > 1000	counts/mV
SMOKE Composites			
Albedo SMOKE	Na, K, and NIR PDs	A(NIR)<0.1, A(K)<0.2, A(Na)>0.7, A(Na)>A(K)>A(NIR)	none
EyeSpy IR Ratio SMOKE	EyeSpy DC	(ES_L+ES_R)/ES_BB > 4.0	none
OmniGuard IR/NIR SMOKE	OmniGuard RefIR, NIR PD	OG_RefIR/(1000*NIR_PD) > 1000	counts/mV
OmniGuard UV/Na SMOKE	OmniGuard UV, Na PD	-300 > OG_UV/Na_PD	counts/mV

[a] While the ratio is counts/count, the count sources are different (EyeSpy and OmniGuard).

Table 89 lists the alarm times for the three COTS VIDS systems, the two OFDs, and the NRL LWVD system for the VS2 Candidate Source Tests, including multiple event algorithms for some systems. The alarm time listed is the earliest alarm time for any of the 8 cameras attached to each system for a particular algorithm. For example, for VS2-019, Camera 2 alarmed at 3 minutes and 22 seconds (00:03:22) after ignition for the SFA Fire algorithm. Blank cells indicate that the system did not generate an alarm for that test/algorithm pair. An entry of NOP indicates that, for a number of reasons, that system was not running for that test and therefore no data was collected. The current LWVD system only processes video from the two deployed nightvision cameras, while the COTS systems analyzes video from six or all eight cameras involved in the test series. Table 90 lists the same information for the VS2 Nuisance Candidate Tests.

The composite values can be broken into two categories, flame and smoke composites. Table 91 lists the time after ignition for any threshold crossing for each of the flame-related composite values for all VS2 Candidate tests. Table 92 presents the same information for the smoke-related composite values.

Table 89 — VS2 Source Candidate Tests COTS VIDS, OFDs, and NRL LWVD Alarm Times

Source Tests	OmniGuard OFD	EyeSpy OFD	SFA FIRE	SFA SMOKE	SignaFire FIRE	SigniFire SMOKE	SigniFire OutOfSight	VSD-8 SMOKE	LWVD
007				00:01:24	00:03:15			NOP [a]	NOP
019			00:03:22		00:02:34		00:03:01	NOP	NOP
010	00:01:36	00:02:42			00:07:19		00:03:46	NOP	NOP
198	00:02:33	00:01:31	00:00:46	00:01:35	00:00:27	00:01:05	00:00:24	02:32	00:00:46
194			00:05:03	00:05:19		00:04:44	00:03:59	06:02	
217	00:18:25			00:03:48		00:10:12	00:10:36	04:03	
120			00:01:39	00:00:57	00:01:13	00:06:02		28:30	00:07:46
121	00:00:00			00:02:30	00:11:08	00:02:31	00:00:15	43:34	00:00:06
102	00:01:50		00:01:42	00:15:09	00:03:12	00:01:55	00:01:32		00:01:47
165			00:11:30	00:06:42		00:06:34	00:00:37	01:03	00:15:00
223			00:12:47	00:05:57	00:13:13	00:08:34	00:06:34	05:21	00:12:32
181								00:11	
114				00:00:43		00:01:18	00:07:13	01:27	00:05:34
177			00:29:56	00:03:00	00:29:39	00:03:25	00:29:39	02:56	00:07:07
064				00:06:07		00:07:38		NOP	NOP
096	00:05:34	00:06:14	00:06:07	00:03:38	00:05:32	00:04:44	00:05:35		00:05:25
168			00:07:11	00:03:01	00:06:48	00:02:46	00:06:54	03:37	00:05:51
158				00:03:20	00:07:38	00:03:41		03:06	00:07:10
178			00:05:42	00:01:15	00:05:15	00:01:24	00:03:58	01:02	00:04:47
180				00:01:39		00:01:44	00:24:48	06:47	

[a] NOP = One or more components of this system were not functioning for this test.

Table 90 — VS2 Nuisance Candidate Tests COTS VIDS, OFDs, and NRL LWVD Alarm Times

Source Tests	OmniGuard OFD	EyeSpy OFD	SFA FIRE	SFA SMOKE	SignaFire FIRE	SigniFire SMOKE	SigniFire OutOfSight	VSD-8 SMOKE	LWVD
133								00:27	
136				00:07:05		00:07:14		00:03	07:33
155			00:01:02		00:18			05:53	00:25
156			00:00:46		00:16			04:11	00:17
209								00:34	
207					02:29			00:20	02:29
131								13:04	
141				00:04:51					
212			00:07:17	00:08:28				03:39	06:35
152				00:05:15		00:05:15		05:15	05:45
145								01:09	
137			00:01:01		01:50		00:01:22	01:56	01:43
154			00:01:23	00:01:18	00:22	00:04:10	00:00:40	00:17	00:23

Table 91 — VS2 Candidate Test SBVS Testbed Flame-Related Threshold Times

Source Tests	Albedo Fire	ES IR Ratio FIRE	OG UV/IR FIRE	ES UV/IR FIRE	OG IR/NIR FIRE	OG UV/NIR FIRE	OG UV/Na FIRE
007	00:02:52	00:11:29					
019	00:00:39	00:02:54	00:00:50		00:05:55	00:00:44	00:01:14
010	00:01:27	00:02:00	00:00:47	00:01:38	00:01:14	00:00:47	00:00:46
198	00:00:40	00:01:29	NOP [a]	00:01:02	NOP	NOP	NOP
194	00:03:31	00:00:00	NOP	00:03:32	NOP	NOP	NOP
217	00:03:22	00:00:00	NOP	00:04:12	NOP	NOP	NOP
120	00:01:29	00:00:00	00:01:35		00:01:49	00:01:45	
121	00:00:00	00:01:53	00:00:00		00:00:00	00:00:00	
102	00:01:20	00:03:24	00:00:00	00:03:04	00:00:45	00:00:45	00:00:24
165		00:00:00	00:03:12				
223	00:06:59	00:17:54	NOP		NOP	NOP	NOP
181		00:00:00					
114		00:13:07	00:07:59		00:09:03	00:07:45	
177	00:00:00	00:02:42	00:28:31		00:28:27	00:09:10	
064			00:25:56		00:31:28	00:24:38	
096	00:05:25	00:05:50	00:05:26	00:05:46	00:05:27	00:05:25	00:04:55
168		00:00:00	00:06:25			00:05:59	
158		00:04:24					
178		00:00:16	00:05:12		00:04:54	00:06:43	
180		00:00:00					
Nuisance Tests	**Albedo Fire**	**ES IR Ratio FIRE**	**OG UV/IR FIRE**	**ES UV/IR FIRE**	**OG IR/NIR FIRE**	**Omni UV/NIR FIRE**	**OG UV/Na FIRE**
133							
136	00:11:07	00:02:50					
155	00:00:11		00:02:25			00:00:17	
156	00:00:13					00:00:17	
209	00:02:07	00:03:15	NOP		NOP	NOP	NOP
207	00:00:34	00:00:37	NOP		NOP	NOP	NOP
131		00:02:47					
141		00:20:06				00:47:00	
212	00:06:45	00:00:00	NOP		NOP	NOP	NOP
152		00:10:52					
145							
137	00:01:01	00:00:37		00:01:03		00:01:01	00:01:03
154	00:00:06		00:00:06	00:00:08		00:00:06	00:00:06

[a] NOP = One or more components of this system were not functioning for this test.

Table 92 — VS2 Candidate Test SBVS Test bed Smoke-Related Threshold Times

Source Tests	Albedo Smoke	ES IR Ratio Smoke	OG IR/NIR Smoke	OG UV/Na Smoke
007	00:03:35			
019	00:06:27	00:08:32	00:06:32	00:03:40
010	00:08:30	00:10:26	00:08:26	00:05:12
198	00:04:02		NOP [a]	NOP
194			NOP	NOP
217	00:12:53		NOP	NOP
120				00:00:35
121	00:04:13		00:00:00	
102	00:14:50		00:04:00	00:03:57
165	00:17:26			00:02:55
223			NOP	NOP
181				00:17:38
114	00:05:19			00:01:19
177	00:31:35			
064	00:16:59			
096	00:08:46	00:08:48	00:05:25	00:06:27
168				
158	00:08:10			
178				00:00:00
180	00:00:00			
Nuisance Tests	**Albedo Smoke**	**ES IR Ratio Smoke**	**OG IR/NIR Smoke**	**OG UV/Na Smoke**
133				
136	00:08:35			00:00:00
155				00:02:59
156				00:01:05
209			NOP	NOP
207	00:02:30		NOP	NOP
131				
141				00:02:03
212			NOP	NOP
152				
145				
137				00:01:31
154	00:01:41			00:00:21

[a] NOP = One or more components of this system were not functioning for this test.

5.10.1 Discussion

The current analysis is based on accuracy as determined by the number of tests correctly identified by the VIDs systems and individual and composite Test bed sensor as fire, smoke or nuisance events. Another way to analyze the data is to consider the response time in addition to simply counting whether or not the sensors respond correctly. Response time comparisons will be included in future test data analyses. It is also important to recognize that the current test was planned primarily to explore the effects of lighting, camera settings and other parameters related to the VIDs systems, so that the text matrix has not been conceived with the intention of including sources that represent all the expected threats on Navy ships. The individual sensor and composite signals are analyzed by characterizing the events in various categories; the results for hazardous conditions are considered for flaming (fire) and smoldering (smoke) events, both in and out of the field of view, where the latter distinction is probably more relevant for flaming events, as well as for nuisances. With this approach it should be possible to identify signal outputs or combinations of them that are accurate for various types of events and therefore identify composite detector configurations that can detect and classify a wide range of scenarios.

In order to distill the information in Tables 89 through 92 into a more digestible form, the results are summarized in Tables 93 through 95 in terms of total and correct event detection, nuisance rejection, false alarms, and total correct classification. Table 93 summarizes the results for the COTS VIDS systems, the COTS OFDs, and the NRL LWVD system. The quantities presented in the table are self-explanatory with the exception of the last row, %'age Correct, which is the sum of correct alarms plus correctly rejected nuisances divided by the total number of tests.

Table 94 provides the summary information for the SBVS Test bed candidate FIRE composite values while Table 95 provides the same information for the Test bed SMOKE composite values. To reiterate, the FIRE and SMOKE nomenclature is based on tentative analysis and the distinction should not be given much weight at this time.

For the COTS VIDS systems, the systems properly classified the 33 Candidate tests with overall success percentages ranging from 50 to 80% with the largest difference coming from correctly detected source events. The Signifire SMOKE and Out Of Sight algorithms, using all eight cameras were the best overall performers, based on an analysis of flame (in and out of Test bed FOV), smoldering, and combined non-FOV flame and smoldering detection source detection, as well as nuisance rejection. While the FireSentry VSD-8 performed well on three of these metrics, it only correctly rejected one of the 13 nuisances, indicating a high level of sensitivity and poor discrimination for these tests. The LWVD also performed well with the exception of nuisance rejection, but correctly rejected 38% of the nuisances, as compared to the 8% rejection rate for the VSD-8. As noted previously, the FOVs of the various systems are different and should be factored into any further detailed analysis. The LWVD systems can only process two video channels at this time, which were dedicated to the two nightvision cameras at camera locations Alpha and Bravo. The COTS VIDS initially were processing all six regular camera inputs, and after additional video splitters were acquired by NRL at test VS2-058, the two nightvision cameras as well. The six regular cameras were distributed throughout the test

compartment as shown in Figure 12. The OFDs were collocated with the Test bed and each other as indicated in Figure 10.

The results for the initially constructed SBVS Test bed composite values indicate that, even at this preliminary stage, their performance is comparable to the video detection systems. Of the FIRE composites, the probability of detecting a flaming event in and out of the Test bed FOV ranged from 50 to 100%. The Albedo FIRE and ES IR Ratio FIRE performed extremely well, detecting all 9 flaming sources. The UV/NIR/IR-based composites performed well in terms of nuisance rejection, with percentages ranging from 85 to 100% of the 13 nuisances rejected. In terms of overall performance, the ES IR Ratio FIRE, OG UV/IR, and OG IR/NIR FIRE composites all scored above 65% total correct classification. The Albedo FIRE composite poorly classified the smoldering events, with the successful hits possibly being due to a smoldering event transitioning to flaming. Also, the reader will notice that the Albedo composite has both a SMOKE and FIRE version, only differing in the applied threshold values. It is possible that further refinement of the albedo composite will produce a more general "event" composite capable of detecting more than one event type.

For the Smoke Composites, moderate performance was observed from all four SMOKE composites, ranging from 50 to 75%. Three composites, not OG UV/Na SMOKE, exhibited good nuisance rejection with percentages above 75%. The Albedo SMOKE exhibited a 77% detection of the flaming sources as well as an overall classification success of 73%, supporting the potential generality of the albedo composite.

Initially, it is rather striking that simple threshold-only alarm criteria using two or more spectrally-resolved detectors could produce comparable results to those of much more sophisticated systems and algorithms. Another significant finding is the general success of the albedo and ES IR Ratio composites which appear to be detecting changes in the test chamber's atmosphere correlated with the generation of smoke and particulates during the source event in addition to the radiation emitted, directly or reflected, from the flaming sources.

Table 93 — Alarm Summary for VS2 Candidate Tests and COTS Systems

COTS Systems	OmniGuard OFD	EyeSpy OFD	SFA FIRE	SFA SMOKE	SignaFire FIRE	SigniFire SMOKE	SigniFire OutOfSight	VSD-8 SMOKE	LWVD
# of FIRE FOV Tests	4	4	4	4	4	4	4	3	3
# of FIRE FOV Alarms	4	2	1	3	3	3	4	3	2
% Correct Alarms	**100%**	**50%**	**25%**	**75%**	**75%**	**75%**	**100%**	**100%**	**67%**
# of FIRE !FOV Tests	5	5	5	5	5	5	5	3	3

Table 93 — Alarm Summary for VS2 Candidate Tests and COTS systems (Continued)

COTS Systems	OmniGuard OFD	EyeSpy OFD	SFA FIRE	SFA SMOKE	SignaFire FIRE	SigniFire SMOKE	SigniFire OutOfSight	VSD-8 SMOKE	LWVD
# of FIRE !FOV Alarms	1	0	4	4	4	3	3	2	2
% Correct Alarms	**20%**	**0%**	**80%**	**80%**	**80%**	**60%**	**60%**	**67%**	**67%**
# of Total FIRETests	9	9	9	9	9	9	9	6	6
# of Total FIRE Alarms	5	2	5	7	7	6	7	5	4
% Correct FIRE Alarms	**56%**	**22%**	**56%**	**78%**	**78%**	**67%**	**78%**	**83%**	**67%**
# of Smolder Tests	11	11	11	11	11	11	11	10	10
# of Smolder Alarms	1	1	6	10	6	10	8	9	8
% Correct Smolder Alarms	**9%**	**9%**	**55%**	**91%**	**55%**	**91%**	**73%**	**90%**	**80%**
# of Nuisance Tests	13	13	13	13	13	13	13	13	13
# of Nuisance Alarms	0	0	5	5	5	3	2	12	8
% Nuisance Reject	**100%**	**100%**	**62%**	**62%**	**62%**	**77%**	**85%**	**8%**	**38%**
# of Total Tests	33	33	33	33	33	33	33	29	29
# of Total Alarms	6	3	16	22	18	19	17	26	20
# of Correct Alarms	6	3	11	17	13	16	15	14	12

Table 93 — Alarm Summary for VS2 Candidate Tests and COTS systems (Continued)

COTS Systems	OmniGuard OFD	EyeSpy OFD	SFA FIRE	SFA SMOKE	SignaFire FIRE	SigniFire SMOKE	SigniFire OutOfSight	VSD-8 SMOKE	LWVD
# of Rejected Nuisances	13	13	8	8	8	10	11	1	5
# of Total False Alarms	0	0	5	5	5	3	2	12	8
% Correct [a]	**58%**	**48%**	**58%**	**76%**	**64%**	**79%**	**79%**	**52%**	**59%**

[a] % Correct = ((Correct Alarms + Correct Rejects)/Total #) for all candidates (source & nuisance)

Table 94 — Threshold Event Summary for VS2 Candidate Tests and SBVS Test bed FIRE Composites

SBVS Test bed[1]	Albedo Fire	ES IR Ratio FIRE	OG UV/IR FIRE	ES UV/IR FIRE	OG IR/NIR FIRE	OG UV/NIR FIRE	OG UV/Na FIRE
# of FIRE FOV Tests	4	4	2	4	2	2	2
# of FIRE FOV Alarms	4	4	2	3	2	2	1
% Correct Alarms	**100%**	**100%**	**100%**	**75%**	**100%**	**100%**	**50%**
# of FIRE !FOV Tests	5	5	4	5	4	4	4
# of FIRE !FOV Alarms	5	5	3	2	3	3	2
% Correct Alarms	**100%**	**100%**	**75%**	**40%**	**75%**	**75%**	**50%**
# of Total FIRETests	9	9	6	9	6	6	6
# of Total FIRE Alarms	9	9	5	5	5	5	3
% Correct FIRE Alarms	**100%**	**100%**	**83%**	**56%**	**83%**	**83%**	**50%**
# of Smolder Tests	11	11	10	11	10	10	10
# of Smolder Alarms	3	10	7	1	5	6	1

[1] "Fire!FOV" = Fires Not in the Fied of View; "Fire FOV" = Fires in the field of view.

Table 94 — Threshold Event Summary for VS2 Candidate Tests and SBVS Test bed FIRE Composites (Continued)

	Albedo Fire	ES IR Ratio FIRE	OG UV/IR FIRE	ES UV/IR FIRE	OG IR/NIR FIRE	OG UV/NIR FIRE	OG UV/Na FIRE
	27%	**91%**	**70%**	**9%**	**50%**	**60%**	**10%**
	13	13	10	13	10	10	10
	8	8	2	2	0	5	2
% Nuisance Reject	**38%**	**38%**	**80%**	**85%**	**100%**	**50%**	**80%**
SBVS Test bed							
% Correct Smolder Alarms	33	33	26	33	26	26	26
	20	27	14	8	10	16	6
# of Nuisance Tests	12	19	12	6	10	11	4
# of Nuisance Alarms	8	1	4	14	6	5	12
# of Rejected Nuisances	5	5	8	11	10	5	8
# of Total False Alarms	8	8	2	2	0	5	2
% Correct [a]	**52%**	**73%**	**77%**	**52%**	**77%**	**62%**	**46%**

[a] %'age Correct = ((Correct Alarms + Correct Rejects)/Total #) for all candidates (source & nuisance)

Table 95 — Threshold Event Summary for VS2 Candidate Tests and SBVS Testbed SMOKE Composites

SBVS Testbed	Albedo Smoke	ES IR Ratio Smoke	OG IR/NIR Smoke	OG UV/Na Smoke
# of FIRE FOV Tests	4	4	2	2
# of FIRE FOV Alarms	4	1	2	1
% Correct Alarms	**100%**	**25%**	**100%**	**50%**
# of FIRE !FOV Tests	5	5	4	4
# of FIRE !FOV Alarms	3	1	2	3

[1] "Fire!FOV" = Fires Not in the Fied of View; "Fire FOV" = Fires in the field of view.

Table 95 — Threshold Event Summary for VS2 Candidate Tests and SBVS Test bed SMOKE Composites
(Continued)

SBVS Test bed	Albedo Smoke	ES IR Ratio Smoke	OG IR/NIR Smoke	OG UV/Na Smoke
% Correct Alarms	**60%**	**20%**	**50%**	**75%**
# of Total FIRETests	9	9	6	6
# of Total FIRE Alarms	7	2	4	4
% Correct FIRE Alarms	**78%**	**22%**	**67%**	**67%**
# of Smolder Tests	11	11	10	10
# of Smolder Alarms	7	1	1	5
% Correct Smolder Alarms	**64%**	**9%**	**10%**	**50%**
# of Nuisance Tests	13	13	10	10
# of Nuisance Alarms	3	0	0	6
% Nuisance Reject	**77%**	**100%**	**100%**	**40%**
# of Total Tests	33	33	26	26
# of Total Alarms	17	3	5	15
# of Correct Alarms	14	3	5	9
# of Missed Alarms	6	17	11	7
# of Rejected Nuisances	10	13	10	4
# of Total False Alarms	3	0	0	6
% Correct [a]	**73%**	**48%**	**58%**	**50%**

[a] % Correct = ((Correct Alarms + Correct Rejects)/Total #) for all candidates (source & nuisance)

A very preliminary analysis of the NRL SBVS Test bed data collected as part of the VS2 Test Series, demonstrates the promise of the optically-based, multi-spectral approach to enhancing the performance of the overall Volume Sensor. Application of very simple, threshold-only selection criteria to composite metrics generated from the pre-processed SBVS Test bed data yielded results comparable to the much more mature COTS systems currently being tested and evaluated for a representative subset of the total data set. The addition of time series analysis (time constants) and further refinement of the composite metrics should only lead to better performance.

6.0 CONCLUSIONS

Real-scale fire tests in mock ship compartments were conducted to collect data of acoustic and spectral sensors and to experimentally evaluate the fire detection performance of three

commercially available video image fire detection systems under various lighting and camera setting configurations. One goal was to establish an understanding of the performance sensitivity and limitations of the VID systems to various setup and environmental conditions that may occur onboard ship. The performance of the detection systems was compared to the response of multiple state-of-the-art smoke detection technologies for a range of fire and nuisance source exposures. Additionally, these tests provided a large database of information to evaluate the spectral and acoustic signatures of the various fire and nuisance sources. Toward this end, microphones, long wavelength video imaging and a test bed of single and multiple element sensors were included in the tests. Based on the testing and analysis performed the following observations and conclusions can be made:

1. When a flaming fire is within the line of sight of the camera the SFA and SigniFire systems can readily detect the fire source with the flame algorithms. When the fire is moved to an obscured location the flame algorithms become ineffective. The exceptions are the SigniFire offsite algorithm, considered an indirect flame algorithm, which maintains the ability to detect obscured flaming fires via detection of reflections, and the NRL LWVD luminosity algorithm, which was specifically designed for sensitivity to reflections. The tests indicate that the offsite algorithm may only be effective in circumstances where relatively bright or sizable reflection areas are in the video image. In circumstances where the fire is across the room from the camera, fully behind obstructions, then the general flickering illumination from the fire may not be sufficient. This diminished performance was observed for the flaming box fires, where the offsite algorithm did not pick up the fire when it was on the other side of the compartment. The NRL luminosity algorithm was sensitive to smaller areas of reflections.

2. The results collected indicate that the effect of potential shipboard background color on VID system fire detection performance is insignificant. Slight trends are indicated favoring the white bulkheads with the older model cameras and gray bulkheads with the newer model camera. The type of fire source and relative location to the field of view of the camera play a much greater role in detection capability and activation times.

3. The testing in the 5.9 x 8.8 x 3.0 m (19.5 by 29 by 10 ft) compartment demonstrated the ability of the VID systems to alarm to a wide range of sources in various compartment locations. Based on these tests, two to three cameras would provide adequate coverage in the test compartment (detecting approximately 94% to 96% of the fire sources). One camera would not be enough to cover this size compartment with the amount of obstructions present. A space with more obstructions located from head height to the overhead, may require additional cameras. Corner locations appear to be the best location for covering large spans of the compartment. However, this is ultimately very dependent on the configuration and the contents of the space.

4. The commercial VID technologies clearly demonstrated the ability to alarm to more sources faster than the spot-type detection system during Test Set 5. Using any two camera combination in the test space, the multi-algorithm SFA and SigniFire systems alarmed to a range of fire sources and source locations with average alarm rates of 93% and 94%, respectively. The corresponding nuisance alarm rates were 33 and 17 percent. The VSD-8 did not perform as well detecting only 63% of the fires in Test Set 5. The EST ion with a 81% detection rate performed the best out of the spot-type detectors followed by the Notifier ion (64%), Notifier photoelectric (60%), and EST photoelectric detectors (59%). The EST ion detectors produce the quickest alarm time in a majority of the flaming fires while the VID systems produced the quickest alarm times during the smoldering sources. When the EST ion detector did produce a quicker alarm during a flaming fire, it was approximately 1.7 minutes before the VID systems. When the VID systems produced a quicker alarm during the smoldering sources, it was approximately 4-7.5 minutes before the spot-type detectors.

5. The passageway provided a space with a different aspect ratio than used in any prior tests. The change in dimensions narrowed the field of view of the cameras. In general, the VID systems had similar alarm responses to fires, such as the flaming boxes and smoldering cable fires, in the passageway and in the compartment. For the flaming boxes with plastic, the systems had similar detection results in the passageway and the compartment, except that the SFA smoke algorithm alarmed to the fires faster by about 1 to 2 minutes. Overall, the passageway did not present any clear identifiable issues for the VID systems that were not identified in the compartment tests for either fires or nuisance sources.

6. The VID systems when supplied with identical camera images, produced by splitting one camera signal into four, produced consistent activation times for smoldering sources and flaming sources within the line of sight of the cameras. The obstructed flaming fires produced inconsistent results, demonstrated by larger standard deviations in alarm times and some cameras producing alarms while others did not. For the obstructed fires, the SFA and SigniFire video detection systems appeared to exhibit a dependence on sequencing and frame grabbing between video input lines that caused large deviations in alarm times and even whether an alarm occurred. This issue are due to the non-simultaneous grabbing of video frames from the different video inputs relative to the random fluctuations of the fire in the video images.

7. When supplied with similar video images, the VID systems produced from six collocated cameras with optimized settings, produced similar results to Test Set 1 (identical camera images) with slightly larger deviations in activation time. Small changes in the image due to slight differences in the fields of view of the collocated cameras, camera settings and model type can change the activation time, but are insignificant when compared to other issues such as compartment coverage, source type, and source location relative to obstructions and the field of view of the camera.

8. Overall the systems demonstrated the ability to detect smoke and fire for numerous camera settings and lighting conditions. The dark contrast and low illumination levels were generally more conducive to detecting flaming fires while the light contrast and high illumination levels were better for detecting smoke. For a few sets of lighting conditions the VID systems did have difficulty detecting some of the sources. The SFA and SigniFire smoke algorithms had difficulty detecting smoke when the compartment was dark (7Fc or red illumination). While the compartment was dark the SFA flame algorithm had difficulty detecting flaming fires with the new model camera and the SigniFire offsite algorithm did not function properly when the old model camera was set to dark contrast. These issues is being discussed with the manufacturer to determine the appropriate camera specifications to maximize usability.

9. The largest deviations in VID system responses were observed with the smoke alarm algorithms during the flaming box fires. The flaming cellulosic material of the boxes generally produced very little visible smoke when burning, particularly at the early stages. The smoke algorithms had significant trouble reliably activating to this kind of burning material. When the VID systems did alarm via a smoke algorithm it was usually later in the burning processes when the fire had penetrated to interior of the boxes and incomplete combustion was occurring, thus producing more visible smoke (i.e., the interior of the box with paper would smolder). Though the smoke algorithms had trouble detecting these fires early, the VID fire algorithms typically detected the flaming boxes when in the cameras line of sight.

10. Application of very simple, threshold-only selection criteria to composite metrics generated from the pre-processed SBVS test bed data yielded results comparable to the much more mature COTS systems currently being tested and evaluated for a representative subset of the total data set. The addition of time series analysis (time constants) and further refinement of the composite metrics should only lead to better performance.

11. The pair-wise analysis of cameras demonstrated that the NRL LWVD system was significantly more sensitive than the commercial video systems to flaming fires in and out of the camera's field of view for collocated nightvision and regular cameras, and as expected, less sensitive to smoldering events. Combining the NRL LWVD system with a commercial video system using *OR* logic increased the probability of event detection while proportionally increasing the probability of nuisance alarm. Conversely, the combination formed using *AND* logic decreased the probability of event detection and probability of nuisance alarm. Restricting the combinatory analysis to flaming fire events, however, showed that the NRL LWVD system detected nearly all the flaming fire events detected by the commercial video systems, plus several others; but it alarmed on a subset of nuisance events that was complementary to the nuisance alarm events of the commercial systems.

12. On a percentage basis, neither the old model cameras (Sony SSC-DC14) nor the new camera models (Sony SSC-DC393) yielded consistently more alarms or faster alarms when the fire was with in the cameras line of sight or at the optimum

settings and illumination. Under red illumination conditions with the SFA fire algorithm, no alarms occurred with the new model cameras whereas the older model cameras did produce alarms. Though the newer model performed poorer for the flame algorithm with the darker red illumination, it demonstrated better performance for the smoke algorithms. For both the SFA and SigniFire smoke algorithms, the newer model cameras with optimal settings detected smoke well whereas the old model cameras had to be set at a light contrast setting to perform comparably. With exception to these relatively extreme cases, the VID systems were able to produce alarms on a rather consistent basis irrelevant of camera model.

7.0 REFERENCES

1. Rose-Pehrsson, S.L., Owrutsky, J.C., Gottuk, D.T., Geiman, J.A., Williams, F.W. and Farley, J.P.,"Phases 1: FY01 Investigative Study for the Advanced Volume Sensor," NRL/MR/6110-03-8688, June 30, 2003.

2. Gottuk, D.T., Harrison, M., Scheffey, J.L., Rose-Pehrsson, S.L., Williams, F.W. and Farley, J.P., "An Initial Evaluation of Video-based Fire Detection Technologies," NRL/MR/6180--04-8737, January 9, 2004.

3. Carhart, H.W., Toomey, T.A. and Williams, F.W., "The ex-USS SHADWELL Full-scale Fire Research and Test Ship," NRL Memorandum Report 6074, Naval Research Laboratory, Washington, DC, revised January 20, 1988, reissued 1992.

4. Wright, M.T., Gottuk, D.T., Darwin, R.T., Back, G.G., Peters, A., Farley, J.P. and Williams, F.W., "CVNX Fire Threat to Ordnance: Revised Test Plan for Test Series 2 - Magazine Detection System Response," NRL Letter Report 6180/0159, April 7, 2003.

5. Gottuk, D.T., Harrison, J.C., Rose-Pehrsson, S.L., M.A., Owrutsky, Williams, F.W. and J. P. Farley "Video Image Detection (VID) Systems and Fire Detection Technologies: Preliminary Results from the Magazine Detection System Response Tests," NRL Letter Report 6180/0262, July 21, 2003.

6. Gottuk, D.T., Harrison, M.A., Rose-Pehrsson, S.L., Owrutsky, J.C., Williams, F.W., and Farley, J.P., "Shipboard Evaluation of Fire Detection Technologies for Volume Sensor Development: Preliminary Results," NRL Ltr Rpt Ser 6180/0282, August 25, 2003.

7. Steinhurst, D.A., Minor, C.P., Owrutsky, J.C., Rose-Pehrsson, S.L., Gottuk, D.T., Williams, F.W., and Farley, J.P., "Long Wavelength Video-based Event Detection, Preliminary Results from the CVNX and VS1 Test Series, ex-USS *Shadwell*, April 7-25, 2003," NRL/MR-MM/6110--03-8733, December 31, 2003.

8. Owrutsky, J.C., Nelson, H.H., Steinhurst, D.A., and Williams, F.W., "Spectral-Based Component of the Volume Sensor Program," NRL Memorandum Report NRL/MR/6110--03-8694, July 30, 2003.

9. Steinhurst, D.A., Owrutsky, J.C., Rose-Pehrsson, S.L., Gottuk, D.T., Williams, F.W., Farley, J.P., "Spectral-Based Volume Sensor Testbed, VS1 Test Series Results, ex-USS S*hadwell*, April 20-25, 2003," NRL Letter Report 6110/075, Naval Research Laboratory, Washington, DC, June 27, 2003.

10. Wales, S.C., Buzasi, D.L., Lynch, J.A., Gottuk, D.T., Rose-Pehrsson, S.L. and Williams, F.W., "Acoustic Event Signatures for Damage Control: Fire and False Alarm Events," NRL/MR/7120/##, Naval Research Laboratory, Washington DC, May 2004, (in press).

11. Wales, S.C., McCord, M.T., Lynch, J.A., Rose-Pehrsson, S.L., and Williams, F.W., "Acoustic Event Signatures for Damage Control: Water Events and Shipboard Ambient Noise," NRL/MR/7120/##, Naval Research Laboratory, Washington DC, April 2004, (in preparation).

12. Gottuk, D.T., Lynch, J.A., Rose-Pehrsson, S.L., Owrutsky, J.C., Steinhurst, D.A., Wales, S.C., Williams, F.W., and Farley, J.P., "Volume Sensor Development Test Plan – Lighting Conditions, Camera Settings, and Spectral and Acoustic Signatures," NRL Ltr Rpt Ser 6180/0326, July 23, 2003.

13. NFPA 72 – National Fire Alarm Code, 2002 Edition, National Fire Protection Association, Quincy, MA, 2002.

14. UL 217, "Standard for Single and Multiple Station Smoke Alarms," Underwriters Laboratories Inc., Northbrook, IL.